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ORIGINAL PAPERS

NOTICE

EFFECT OF MICROWAVE HEATING ON 3-MCPD AND GLYCIDYL ESTER CONTENT OF VEGETABLE OILS

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ABSTRACT

The study aims to investigate the changes in 3-MCPD and glycidyl ester content of vegetable oils during microwave heating. For this purpose, three different refined vegetable oils (canola, hazelnut, sunflower) were exposed to microwave energy at three power settings (350, 460, 700 watt) for four different periods (1, 3, 5 and 10 minutes). The heated oil samples were evaluated for their 3-MCPD and glycidyl ester contents using alkali transesterification with DGF Standard Method C-VI 18 (10). Results have shown that canola oil presented lower concentrations of 3-MCPD esters throughout the microwave heating process. Glycidyl ester levels were determined to clearly increase at oils heated at 700 W for 10 minutes.

KEYWORDS:
3-MCPD ester, glycidyl ester, heating, microwave

INTRODUCTION

3-Monochloropropane-1,2-diol (3-MCPD) is a food processing contaminant which might be formed during processing of various fat containing matrices at elevated temperatures in the presence of chloride sources [1, 2]. 3-MCPD belong the group of chloropropanols which consists of 5 main compounds including 2-monochloropropane- 1,3-diol (2-MCPD), 3-monochloropropan-1-ol, 1,3-dichloropropan-2-ol (1,3-DCP), 2,3-dichloropropan1-ol (2,3-DCP) and 3-monochloropropane-1,2-diol 3-MCPD [3]. The formation of 3-MCPD esters was firstly reported by Zelinková et al. [4] in refined vegetable oils and the concentrations of 3-MCPD esters were determined to be up to 2.46 mg/kg. 3-MCPD esters have been reported to be mainly formed during deodorization step of oil refining [5].

Glycidyl esters are known as analogous compounds of 3-MCPD esters and it has been assumed that glycidyl esters are also formed during deodorization step of oil refining process [6], thus they are mainly found in refined oil and vegetable-fat containing foodstuff. Glycidol, which has been reported as a possible genotoxic carcinogenic compound for humans [7], is formed by disintegration of glycidyl esters during digestion [8]. Considerable number of works have been conducted in the last decade to display the analysis techniques of those process contaminants, mitigation studies, toxicological research and regulatory studies. Still, a number researches are ongoing in order to bring more clearance and further undestanding of those contaminants.

Microwave ovens have gained increasing interest due to their ease of use and fast heating advantages. Microwave energy is commonly utilized in food industry processes for several purposes such as roasting, drying, blanching, dehydration, cooking, frying, pasteurization and sterilization. During microwave heating, oils and fats undergo some physical and chemical changes. Numerous studies have been performed to evaluate the effect of microwaves on nutritional values and compositional parameters of oils and fats. However, to the best of author's knowledge, there is no study investigating the 3-MCPD and glycidyl ester formation in vegetable oils during microwave heating. Thus, the objective of the current work was to study the change in 3-MCPD and glycidyl ester contents of three selected oils (hazelnut, sunflower, corn) exposed to microwave heating for different periods and power settings.

MATERIALS AND METHODS

Reagents and standards. Toluene, *tert*-butyl methyl ether (tBME), methanol, hexane, ethyl acetate, diethyl ether, *iso*-octane, sodium methoxide, sodium chloride, sodium bromide, sodium sulphate, phenyl boronic acid and d5-3-MCPD-1,2-*bis*-palmitoyl ester, 3-MCPD and glycidol were purchased from Sigma (St-Louis, USA).

Microwave heating. Refined canola, refined hazelnut and refined sunflower oils were obtained from local markets. 50 ml of samples were weighted into dark glass bottles and placed in the middle of rotating plate of a domestic microwave oven (Arçelik, MD 574 S, 17 L, 2450 Hz). Oil samples were heated at three power settings (350, 460 and 700 watt) for 1, 3, 5 and 10 minutes. Between tests, the microwave oven door was left open and the inside of the oven was cooled using an electrical fan so that the oven cavity temperature was reduced to room temperature before the next test. All heating processes were performed twice and heated samples were analyzed at least two times. Heated oil samples were kept at -18 °C in nitrogen atmosphere until analysis.

Analysis of 3-MCPD and glycidyl esters. The concentrations of 3-MCPD and glycidyl esters were determined according to the DGF Standard Method C-VI 18 (10) [9]. The chromatographic separation was achieved by gas chromatography-mass spectrometry using a capillary column (Restek Rxi-5 MS column, 30 m × 0.25 mm × 0.25 µm) and the injector was run in splitless mode. Helium was the carrier gas with a constant flow rate of 1.18 mL/min. The oven temperature program was set as follows: 80°C raised to 155°C with a heating rate of 5°C/min and then it was raised to 300°C with 60°C/min and held for 5 minutes. Temperature of ion source and interface in mass spectrometer was 200 and 280 °C, in the same order. Quantification of the results was done by monitoring characteristic ions at m/z 150 for 3-MCPD-d5 and m/z 147 for 3-MCPD.

Statistical analysis. Statistical analysis was carried out using SPSS 15.0 statistical software (SPSS Inc., Chicago, USA). Data were evaluated by one-way ANOVA using Duncan's multiple range test to determine any significant differences. A *p*-value of less than 0.05 was considered significant.

RESULTS AND DISCUSSION

The change in 3-MCPD ester contents of vegetable oils exposed to different microwave heating periods at 350, 460 and 700 watt power settings were given in Table 1. Hazelnut oil presented relatively higher 3-MCPD ester contents throughout the heating period than other oils. Sunflower oil was the second in terms of 3-MCPD concentration and the samples contained 0.46-1.01mg/kg of 3-MCPD ester in accordance with the results reported in previous studies [6, 10]. Canola oils contained the lowest level of 3-MCPD esters of which 0.07-0.27 mg/kg at 350 W, 0.10-0.32 mg/kg at 460 W and 0.09-0.20 mg/kg at 700 W of microwave heating. 3-MCPD ester concentrations of canola oil was similar to results obtained by Zelinková et al. [4]. The low capability of virgin canola oil to form 3-MCPD esters was also previously reported by Matthäeus et al. [11].

TABLE 1
3-MCPD ester content of oils exposed to microwave heating at different power settings and times (mg/kg)

Microwave power	Time	Oil type		
		Canola	Sunflower	Hazelnut
Unheated		0.37^{d}	0.61^{bcd}	0.56^{a}
350 W	1 min	0.07^{a}	0.69^{de}	0.69^{bc}
	3 min	0.27^{c}	0.54^{abcd}	0.84^{de}
	5 min	0.26^{c}	0.73^{ef}	1.14^{g}
	10 min	0.15^{b}	0.50^{ab}	1.26^{h}
460 W	1 min	0.32^{cd}	0.45^{a}	1.28^{h}
	3 min	0.11^{ab}	0.65^{cde}	0.80^{cd}
	5 min	0.10^{ab}	0.56^{abcd}	0.90^{ef}
	10 min	0.12^{ab}	0.54^{abcd}	0.91^{f}
700 W	1 min	0.20^{ab}	1.01^{g}	0.84^{de}
	3 min	0.12^{ab}	0.51^{abc}	0.81^{cde}
	5 min	0.10^{ab}	0.46^{ab}	0.58^{ab}
	10 min	0.09^{ab}	0.59^{f}	1.87^{i}

Values in each column with different letters are significantly different at $p<0.05$.

TABLE 2
Glycidyl ester content of oils exposed to microwave heating at different power settings and times (mg/kg)

Microwave power	Time	Oil type		
		Canola	Sunflower	Hazelnut
Unheated		0.13^{bc}	0.11^{ab}	0.05^{a}
350 W	1 min	0.12^{abc}	0.08^{ab}	0.16^{c}
	3 min	0.14^{bc}	0.11^{ab}	0.08^{a}
	5 min	0.13^{c}	0.10^{ab}	0.08^{ab}
	10 min	0.10^{ab}	0.08^{ab}	0.06^{a}
460 W	1 min	0.11^{abc}	0.12^{ab}	0.21^{c}
	3 min	0.10^{a}	0.11^{ab}	0.14^{c}
	5 min	0.10^{ab}	0.04^{a}	0.11^{bc}
	10 min	0.13^{bc}	0.16^{b}	0.24^{d}
700 W	1 min	0.10^{a}	0.05^{ab}	0.09^{ab}
	3 min	0.09^{a}	0.04^{a}	0.16^{c}
	5 min	0.13^{bc}	0.03^{a}	0.21^{d}
	10 min	1.07^{d}	0.48^{c}	4.04^{e}

Values in each column with different letters are significantly different at $p<0.05$.

Glycidyl esters, together with 3-MCPD esters, are food process contaminants that occur at high temperatures and pose concern for human health [12]. The changes in glycidyl ester concentrations of different vegetable oils during microwave heating at 350, 460 and 700 watt were given in Table 2. The glycidyl ester contents of canola, sunflower and hazelnut oils ranged in 0.10-1.07 mg/kg, 0.03-0.48 mg/kg and 0.05-4.04 mg/kg, respectively. The glycidyl ester amounts of sunflower oils were found to be lower than hazelnut and canola oils throughout microwave radiation. Microwave heating process caused significant but slight differences in the the glycidyl ester concentrations of the vegetable oils heated at 350 W and 460 W. Nonetheless, the clear and high increase at the glycidyl ester levels were observed at samples heated at 700 W for 10 minutes

CONCLUSION

The results reported herein expose the first knowledge about the effect of microwave exposure on 3-MCPD and glycidyl ester content of vegetable oils. The current data may contribute to the ongoing studies related the formation of 3-MCPD and glycidyl esters in different heat-induced food processes, since microwave technology assists a number of food operations, as well.

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KNOWLEDGE AWARENESS AND PRACTICE OF VITAMIN D AMONGST ADULTS LIVING IN THE QASSIM AREA BEFORE AND AFTER COVID-19 PANDEMIC

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ABSTRACT

As the number of populations around the world affected by vitamin D deficiency and insufficiency and its associated disease are in increase, the correct knowledge, awareness and practices about vitamin D benefits on health to avoid and prevent diseases should also be increased. Therefore the present study aims to examine the Knowledge, awareness and practices about vitamin D of adults living in the Qassim region before and after the emergence of COVID-19. A cross-sectional survey was conducted among 195 of the general adult population in the Qassim region, Saudi Arabia from 15th September 2020 to 25th October 2020. The results revealed that a high percentage of participants know about vitamin D (93.8%). Also, it has appeared that there was no association between knowledge and awareness of vitamin D and age, gender, education or social status. Around 82.6 % of the participants know the sources of vitamin D and the majority of participants like exposure to the sun (79%), where the most time exposed to the sun in the early morning and after 3 pm was reported to be 43.6% and 52.3%, respectively. In addition, about 35% of participants increased their knowledge of vitamin D after the emergence of COVID-19. A high percentage of participants thought that vitamin D raising the body immunity against viral infection or improve immunity in general and around 67.7% thought that vitamin D prevents or increase resistance to COVID-19. From the foregoing results, it could be concluded that the high level of knowledge and awareness about vitamin D in general adult living in the Qassim region and increased knowledge after the emergence of COVID-19 are the most important result of the current study.

KEYWORDS:
Vitamin D, COVID-19 pandemic, Knowledge, awareness, Sun, exposure

INTRODUCTION

Vitamin D is considered an immunomodulatory agent and its hormonal action related to the maintenance of mineral and skeletal homeostasis is essential for maintaining a healthy skeleton. The main function of vitamin D is to regulate the metabolism of calcium and phosphate in the body ([1, 2]

The primary source of vitamin D in the human body is from the exposure of skin to ultraviolet light which represents more than 90% of vitamin D needed for human. The 7-dehydrocholesterol under the skin is converted ultraviolet light band B (UVB) to an inactive precursor vitamin D3 (cholecalciferol). The remaining human need of vitamin D (10 %) is gained from different food sources rich in vitamin D [3]. However, many factors can affect the synthesized of vitamin D for UVB under the skin such as latitude, pollution, solar zenith angles, ozone layer and pigmentation [2].

Vitamin D deficiency is a global public health problem. Around 1 billion people worldwide suffer from vitamin D deficiency [4], In this regard, Vitamin D Deficiency is common in in Saudi Arabia population [5, 6]. The experts work in Prince Mutaib Chair for Biomarkers of Osteoporosis task force in Saudi Arabia have been defined the sufficient level of vitamin D as circulating serum 25(OH) D (≥50 nmol or ≥20 ng/ml) for the general population [7], similarly to the IOM, USA that the recommended cut-off of vitamin D status 25(OH) D is (20 ng/ml or 50 nmol/L) for normal healthy people as the main basis of bone health.

In recent years many studies have been reported that vitamin D deficiency associated with common chronic diseases such as cardiovascular diseases, cancer, diabetes and immune system diseases [8]. In addition, it has been reported that vitamin D involved in regulating immune function, inhibiting inflammatory reactions, autoimmune diseasesas well as immune cell biology system [9, 10].

The lack of knowledge and practice about vitamin D in additions to the wrong lifestyle, indoor activity, extensive cloths cover as well as lack of regular exposure to sunlight can be considered the major cause of Vitamin D deficiency among the Saudi population. So, the increase in knowledge, awareness and importance of effective practices about vitamin D is important for the general population to know about the benefits on health especially on the Prevention of diseases related to deficiency and insufficiency. Therefore, the current study aims to examine the Knowledge, awareness and practices about vitamin D of adults living in the Qassim region before and after the emergence of the COVID-19 pandemic.

MATERIALS AND METHODS

Questionnaire. For data collection, a cross-sectional survey was conducted among the general adult population in the Qassim region, Saudi Arabia from 15th September 2020 to 25th October 2020. An electronic self-administered questionnaire (Google form) consisting of five parts was used to collect data (socio-demographic characters, health and anthropometric data, knowledge and awareness of vitamin D, attitude and practices of an individual about vitamin D and sun exposure and awareness associated after COVID-19 pandemic). The questionnaire was designed by the author and validated by three arbitrators in the study area. The questionnaire was previously tested for reliability and accuracy among 20 participants.

Statistical analysis. Data were statistically analyzed using descriptive statistics using IBM SPSS statistics for mac version 25.0 (SPSS Inc., Chicago, IL). Descriptive statistics were used to characterize the participants of the study population. Data were presented as a percentage in frequency tables for each part of the questionnaire to identify the participant's Socio-demographic characters information, Knowledge and awareness of vitamin D, Sun exposure and practices about vitamin D and Awareness of vitamin D after the emergence of COVID-19. A Chi-square test was conducted to identify the association between knowledge and awareness of vitamin D and each of age, gender, education and social status, at the significance level of $p \leq 0.05$.

Ethics statement: The questionnaire and data collection, a cross-sectional survey were approved by the ethics Committee of Health Resesrch Ethics, Deanship of Scientific Research, Qassim University, 20-06-13.

RESULTS

Socio-demographic characters information. One hundred and ninety-five participates have been completed the survey, table 1 have shown the socio-demographic characters information, aged of participants were 59% between 18-35 years, 33.8% between 36-50 years and 7.2% over 50 years. Most of the participants were male (61.5%), different

TABLE 1
Socio-demographic characters information

Question	Mean	SD
Weight (Kg)	69.9	23. Apr
Hight (cm)	162.3	15. Sep
	N	**%**
Age (year)		
18-35	115	59
36-50	66	33.8
>50	14	07. Feb
Gender		
Male	120	61.5
Female	75	38.5
Education		
High school	24	12. Mrz
Diploma	18	09. Feb
Bachelor degree	142	72.8
Higher degree	11	05. Jun
Job		
Unemployed	37	19
Free business	6	03. Jan
Housewife	1	0.5
Student	108	55.4
Retired	8	04. Jan
Teacher	2	1
Government employee	23	11. Aug
Private employee	10	05. Jan
Social status		
Wido/widower	1	0.5
Unmarried	123	63.1
Married	67	34.4
Separated	4	02. Jan
Have you been diagnosed with a chronic disease?		
Yes	32	16. Apr
No	163	83.6

TABLE 2
Knowledge and awareness of vitamin D

Question	N	%
Do you know about vitamin D?		
Yes	183	93.8
No	12	06. Feb
Is the vitamin D in the body?		
Yes	159	81.5
No	36	18. Mai
Sources of vitamin D:		
Sun light	28	14. Apr
vitamins Supplement	3	01. Mai
Some foods	1	0.5
All the above	161	82.6
I do not know	2	1
Dose vitamin D effect on health:		
Good	148	75.9
Bad	32	16. Apr
I do not know	15	07. Jul
Do you know is vitamin D good for bone health?		
Yes	176	90.3
No	3	01. Mai
I do not know	16	08. Feb
Is vitamin D deficiency related to muscle pain?		
Yes	133	68.2
No	12	06. Feb
I do not know	50	25. Jun
Do you think that vitamin D deficiency has related to other health conditions in the body such as heart disease / diabetes / depression / high blood cholesterol / cancer / multiple sclerosis / insomnia or insomnia or asthma)?		
Yes	99	50.8
No	24	12. Mrz
I do not know	72	36.9
Sources of knowledge about vitamin D?		
Newspapers and magazines	3	01. Mai
TV and radio	16	08. Feb
Friends and relatives	97	49.7
Social Media	104	53.3
Doctors in net and social sites	92	47.2
Doctors in clinics and hospitals	66	33.8
Health Publications, Brochures	46	23. Jun
Scientific books in schools and universities	55	28. Feb
Are you ready to check the level of vitamin D in the body?		
Yes	181	92.8
No	14	07. Feb
If you are diagnosed with a deficiency in the level of vitamin D, will you take vitamin D as a dietary supplement (tablets / injection ...) to treat the deficiency?		
Yes	181	92.8
No	14	07. Feb

education levels were found in this survey were the most of them have the bachelor degree (72.8%). In this survey almost half of participants were student (55.5%) and 63.1% participants were unmarried. In regarding to the health most of the participants were not diagnosed with a chronic disease (83.6%).

Knowledge and awareness of vitamin D. Data presented in table (2) show the knowledge and awareness of vitamin D. The most of participants (93.8%) knew that vitamin D is essential for health. There was no significant association between knowledge and awareness of vitamin D and each of age, gender, education and social status. About 82.6 % of the participants answered with their awareness of the sources of vitamin D, on the contrary about 14 % of participants thought that the only source of vitamin D is the sunlight. In this survey, 75.9% and 90.3% of the participants have known that vitamin D has a good effect on health and it is good for bone health, respectively. In addition, vitamin D deficiency has been known to be related to muscle pain and other health issues (68.2% and 50.8%, respectively). The main sources of knowledge about vitamin D were from social media, friends, doctors on the internet and social sites (53.3 %, 49.7% and 47.2% respectively). Majority of the participants were ready to measure the concentration of vitamin D in the body and will take vitamin D as a dietary supplement (tablets/injection) to treat the deficiency if they diagnosed with a deficiency. There was no significant association have been found between knowledge of vitamin D and each of age, gender, education and social status.

Sun exposure and practices about vitamin D. The majority of participants (79%) had a sun exposure. About half of participants (52%) had sun exposure after 3 pm. However, 43.6 % of the volunteers had a sun exposure in the early morning.

Data in Table (3) indicate that 68.2% of the sample population thought that most parts of the body exposed to the sunlight are enough for them to cover their vitamin D needed. Almost half of the participants were done a test of vitamin D level and about 64% of participants suffered from vitamin D deficiency or insufficiency and 89% have been taken supplement after their test. On the other hand, 42.1% have been taken supplements without doing the test of vitamin D, which were the most reasons to raise immunity and prevent diseases, an increase in health and to treat the pain 44.3%, 39.6% and 38.7% respectively. In this survey, doctors were the most one where the participants have taken advice on vitamin D supplementation 65.7% then friends and related 20.1%. Sixty-one of participants didn't know the adequate level of vitamin D in the body. Milk and dairy products, fatty fish were the most foods were reported as rich in vitamin D.

TABLE 3
Sun exposure and practices about vitamin D

Question	N	%
Would you like to be exposed to the sun?		
Yes	154	79
No	41	21
Do you usually protect yourself from the sun?		
Yes	40	20. Mai
No	32	16. Apr
Some time	123	63.1
Do you use sunscreen?		
Yes	45	23. Jan
No	102	52.3
Some time	48	24. Jun
If you a person who exposed to the sun, what is your usual time?		
6-8 am	85	43.6
8-10 am	50	25. Jun
10 am-12 pm	39	20
after 3 pm	102	52.3
What parts of your body are exposed to sunlight?		
Face	141	72.3
Hands	148	75.9
Feets	90	46.2
Hands to elbows	104	53.3
Legs	43	22. Jan
Face and neck	104	53.3
Other parts of the body	15	07. Jul
Do you think your time in the sun is enough for you to get vitamin D?		
Yes	31	15. Sep
No	133	68.2
I do not know	31	15. Sep
Have you ever done a test on the level of vitamin D in the body?		
Yes	106	54.4
No	89	45.6
What are the reasons for the analysis of vitamin D?		
Doctor prescription	-	31
Personal decision	-	56
Other reason	-	13

What was the result of the analysis?		
Deficiency	76	63.9
Insufficiency	14	11. Aug
Sufficiency	9	07. Jun
I do not know	20	16. Aug
Did you take a vitamin D supplement after the analysis?		
Yes	89	73
No	33	27
Have you ever taken a vitamin D supplement or a group of nutritional supplements that contain vitamin D without having analysis?		
Yes	82	42.1
No	113	57.9
What are the reasons for taking these nutritional supplements that contain vitamin D?		
An increase in health	42	39.6
To raise immunity and prevent diseases	47	44.3
Experiment	8	07. Mai
To treat the pain you suffer from	41	38.7
Other	9	08. Mai
Have you taken vitamin D supplements with advice from ...		
A doctor	88	65.7
pharmacist	15	11. Feb
Friend or relative	27	20. Jan
The impact of social media	9	06. Jul
After reading the health and medical awareness publications	23	17. Feb
Other	14	10. Apr
Do you know how much vitamin D is needed from nutritional supplements?		
Yes	69	35.4
No	126	64.6
What is the source or reference for you to know the necessary amount of vitamin D for the body?		
Doctor or pharmacist	66	67.3
Friends or relatives	6	06. Jan
Publications Health and Medical Awareness	18	18. Apr
Other	22	22. Apr
Do you know what is the adequate level of vitamin D in the body?		
Yes	76	39
No	119	61
What is the adequate level of Vitamin D in the body?		
< 10 ng/ml	2	02. Feb
10-30 ng/ml	11	12. Jan
30-100 ng/ml	29	31.9
> 100 ng/ml	49	53.8
Do you know what foods are rich in vitamin D?		
Milk, dairy products	120	61.5
Red meat	28	14. Apr
Chicken	9	04. Jun
Fatty fish	120	61.5
Fruit	60	30. Aug
Vegetables	67	34.4
eggs	78	40
Baked goods	4	02. Jan
Legumes	30	15. Apr
Butter	23	11. Aug
Mushroom	33	16. Sep

Awareness of vitamin D after COVID-19 pandemic. About 35% of participants improved their knowledge and attitude about vitamin D after COVID-19 pandemic. A high percentage of participants thought that vitamin D raises the body immunity against viral infection or improve immunity in general and around 67.7% thought that vitamin D prevents or may aid in the resistance of respiratory infections such as COVID-19. The pandemic of COVID-19 has affected 23.6% of participants in their choices of food rich in vitamin D. only 11.3% of participants have been diagnosed with COVID-19 and 38% and 41.2% of them have been informed by doctors to take dietary supplements of vitamin D and expose to sunlight, respectively to enhance their immunity (Table 4).

DISCUSSION

Vitamin D deficiency is a public health issue around the world [11 ,12] even in a country with sunshine most of the year [13, 5]. Knowledge, awareness and practices about vitamin D may differ between communities and population. The present study is one of the first studies to examine the knowledge, awareness and practices of vitamin D before and after the emergence of COVID-19 among adult living in Qassim region.

The finding of this study showed that most of the participants knew about vitamin D, with a majority knew the right sources of vitamin D and knew that vitamin D is good for their general health and bone. Almost half of the participants in this study thought that vitamin D deficiency related to some health conditions such as heart diseases, diabetes, depression, high blood cholesterol, cancer, multiple sclerosis and asthma. Previously, published studies related to vitamin D deficiency and some of those health conditions were reviewed by Wang [8].

The highest sources of knowledge about vitamin D were from social media then friends and relatives and doctors on the internet and social site, which showed the high impact of social media in population to increase different knowledge of health [14].

TABLE 4
Awareness of vitamin D after the emergence of COVID-19

Question	N	%
Before emergence of COVID-19	183	93.8
After the emergence of COVID-19	6	03. Jan
Do not have knowledge	6	03. Jan
Is the emergence of COVID-19 affected you by increase your knowledge?		
Yes	69	35.4
No	126	64.6
Do you think there is relationship between vitamin D and raising the body immunity against viral infection or for improving immunity in general?		
Yes	167	85.6
No	28	14. Apr
Do you think there is a relationship between vitamin D and prevention or resistance of COVID-19?		
Yes	132	67.7
No	63	32.3
Did you ensure to take the adequate level of vitamin D throughout emergence of COVID-19?		
Yes	71	39.4
No	109	60.6
Has the Covitd-19 pandemic affected your choices of food rich in vitamin D?		
Yes	46	23. Jun
No	149	76.4
Have you ever been diagnosed with COVID-19?		
Yes	22	11. Mrz
No	173	88.7
After infected with COVID-19, have you been informed by doctors to take dietary supplements of vitamin D to raise immunity?		
Yes	8	38
No	13	62
After infected with COVID-19, have you been informed by doctors to expose to sunlight to rise immunity?		
Yes	7	41.2
No	10	58.8

In reflecting on the results of high knowledge and awareness of participants about vitamin D, most of them are ready to measure vitamin D concentrations and they are interested to treat the deficiency if they are diagnosed with vitamin D deficiency. Thus, this attitude can help the community to increase health status and prevent any related health issue related to vitamin D deficiency in the future.

The main source of vitamin D is sunlight [15]. In the current investigation, almost 80% of participants like to exposed to the sun, and a few have been reported in this survey usually protect themselves from the sun where the other not or some time and about half of the participants not used sunscreen. The usual time exposed participants to sunlight was in the early morning 6-8 am and after 3 pm which is not the time to get vitamin D from sunlight as it has been reported before the perfect time to get vitamin D from sunlight in summer and winter after 9:00 am to 10:30 am, 2:00 pm to 3:00 pm and 10:00 am to 2:00 pm, respectively [7].

Face and hands then hands to elbows and face and neck were the most part of the body exposed to sunlight in this survey which reflects the traditional clothes of this population in Qassim city, however, most of the participants thought the time exposed to the sunlight is not enough to get vitamin D as previously reported 3-4 times a week and exposed 20% of their body to get vitamin D from sunlight [7].

About half of participants have done a test to check the vitamin D level in the body and the most reason for analysis of vitamin D level of the participants was a personal decision which reflects well educate and knowledge of participants in this survey about the importance of vitamin D in the body. Their results of vitamin D level were classified as a deficiency (~64%), insufficiency (~12%), sufficiency (~7%) and don't know the results (~17%) the majority have been taken vitamin D supplement after did the analysis of vitamin D to treat the deficiency as usually describe to increase the level of vitamin D in the body [16]. However, around 42% of the participants have been taken vitamin D supplement or group of nutritional supplements that contain vitamin D without having done the analysis of vitamin D as their most reason of taken these supplements to raise immunity and prevent diseases, increased their health and to treat the pain they suffer from. Most one has been taken the advice to take these supplements from a doctor (~65%), friend and relative (~20%) and after reading health and medical awareness (~17%) and the impact of social media was the lowest (~6%).

In this study, most of the participants do not know the adequate level of vitamin D in the body and around half of the participants picked that (> 100 ng/ml or 250 nmol/L) is the adequate level of vitamin d in the body. The recommended cutoff level of vitamin D by IOM, USA is (20 ng/ml or 50 nmol/L) for normal healthy people as the main basis of bone health whereas the range below (30 ng/ml or 75nmol/L) of 25(OH) D concentration is considered vitamin D deficiency by Holick, [17].

At the end of the year 2019 and the appearance of COVID-19 around the world, people thought about their body immunity and how to increase it to protect their health from diseases. The awareness of vitamin D after the emergence of COVID-19 was examined in this study, as the results showed in the second part of this survey the majority of participants have been knowing about vitamin D (93.8%) and a small percentage (~3%) of the participants knowing about vitamin D after the emergence of COVID-19. However, (~35%) of participants reported that the emergence of COVID-19 affected them by increasing their knowledge about vitamin D.

The association between vitamin D and body immunity have been reported previously [18] and in this study, the majority of participants (85.6%) thought there is a relationship between vitamin D and rising the body immunity against viral infection or for improving immunity in general. Around 67% of the participants thought there is a relationship between vitamin D and prevention or resistance of COVID-19, their thought may be related to the immunity system in general in the body because still unknowing in this relation there were a few reports about this were published [19].

In this study, some participants (~39%) and (~23%) ensured the adequate level of vitamin D throughout the emergence of COVID-19 and affected their choices of food rich in vitamin D respectively, as the emergence of COVID-19 has a good impact on participants in their practices and choices about vitamin D.

A few participants in this study have been diagnosed with COVID-19, interesting that some of the participants after infected with COVID-19 have been informed by doctors to take dietary supplements of vitamin D and to expose to sun light to raise immunity in the body. Which is supports the importance of an adequate level of vitamin D in the body [18, 19].

CONCLUSION

The high level of knowledge and awareness about vitamin D in general adult living in the Qassim region were reported. There was no association between knowledge and awareness of vitamin D and each any of age, gender, education or social status. The majority of participants under the current study knows the sources of vitamin D and like to exposure to the sunlight, where the most time exposed to the sun in the early morning and after 3 pm. The high knowledge of participants about vitamin D and their importance was formed different sources were the highest social media then friends and relatives and doctors on the internet and social sites. Participants increased their knowledge of vitamin D after the emergence of COVID-19, majority of participants thought that vitamin D raises the body immunity against viral infection or improve immunity in general and thought that vitamin D prevents or increase resistance to COVID-19.

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THE PRESENCE OF FOODBORNE PATHOGENS IN RETAIL TABLE EGGS SOILED WITH FECES

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ABSTRACT

Eggs are consumed as human food throughout the world and considered a very nutritious and a cheap source of protein. Most of the eggs produced in the world are presented to consumers as whole shell eggs, table eggs. Eggs can be contaminated with microorganisms both horizontally and vertically, therefore it might be a vector of microorganisms causing foodborne illness in humans. The presence of various foodborne pathogens in the contents and on the shell surface of table eggs soiled with feces was studied in this study. For this purpose**,** a total of 412 egg samples (206 pooled samples of 2 eggs) were purchased from 16 separate retail locations and analyzed for *Salmonella*, *Campylobacter* and *Listeria*. In the result of the study, *Salmonella* spp., *Campylobacter* spp. and *Listeria* spp. were detected on the eggshell surfaces samples, 1.45%, 0.97% and 2.42% respectively. Neither of those pathogens was isolated from the egg content samples. Confirmed isolates were identified as *Salmonella* Infantis, *Campylobacter jejuni*, *Listeria monocytogenes, Listeria innocua* and *Listeria grayi.* The results of the study showed that *Salmonella*, *Campylobacter* and *Listeria* species which are important foodborne pathogens, can be shed with eggs soiled with feces. Selling these eggs to consumers might pose a public health and safety risk for humans. In the concept of safe food from farm to fork, carrying the control programmes to the points of retail sale of eggs would be beneficial.

KEYWORDS:
Egg, contamination, feces, foodborne pathogens

INTRODUCTION

Egg, which contains nutrients required for the human body, is one of the animal food sources that should be emphasized in solving the problem of unbalanced nutrition. It plays an important role in a healthy diets as it is rich in essential amino acids and contains many vitamins and minerals [1]. Microbial contamination of eggs increases the food poisoning risk for the consumer, and outbreaks originating contaminated eggs have been reported worldwide [2,3].

Shell eggs from healthy chickens are assumed sterile inside, but it could be contaminated with different bacterial species, either vertically or horizontally. In vertical transmission, the yolk, the albumen and/or the membranes are directly contaminated as a result of bacterial infection of the reproductive organs. Horizontal transmission occurs from the penetration of the shell by bacteria deposited on the surface of the egg after laid. This is usually caused by fecal contamination in the eggshell, and also from the contamination through environmental vectors such as farmers, pets and rodents [4,5]. Various enteric bacteria can be found in the eggshells and egg content of table eggs [6]. The most prevalent pathogen of eggs is *Salmonella* serovars*,* and they could be isolated from eggshells and egg contents. *S.* Enteritidis and *S*. Typhimurium are the most frequently determined *Salmonella* serotypes in the eggs and egg products causing food poisoning as well as the other *Salmonella* serotypes, and the outbreaks caused by eggs and egg products are mostly associated with *S.* Enteritidis [7] In the European Union (EU), 36.8% of the outbreaks caused by *Salmonella* spp. in 2017 were reported to be associated with the consumption of eggs and egg products, the majority of these outbreaks (31.3%) were caused by *S.* Enteritidis [8]. Eggs and egg products are also susceptible to contamination by other pathogens, such as *Campylobacter* spp. and *Listeria monocytogenes* [4,7]. *Campylobacter* spp., especially *C. jejuni* and *C. coli,* are commonly found as a commensal organisms in the gastrointestinal and reproductive tracts of poultry. *Campylobacter* spp. have been isolated from eggshell and different samples of laying hens such as feces, cloacal swab, caecum and magnum. [9-11]. Likewise, *Listeria* spp. including *L. monocytogenes* has been isolated from feces and environmental samples of laying hens [12], the raw liquid whole eggs [13], the water used for washing shell eggs [14] and the vacuum loaders in shell egg processing facilities [15]. *L. monocytogenes* also appears to be fairly resistant under storage and handling conditions of shell eggs [13,16]. All of these sources fortify the existence of *Campylobacter* spp. and *Listeria* spp. on shell eggs.

Numerous microorganisms might be present on the eggshell [17]. Contamination of the eggshell by the excreate increases the numbers of microbes on the eggshell, thus increasing the risk of bacterial contamination of egg content [18]. It has been also reported that soiled or visually dirty eggs were found to be a common risk factor in outbreaks [19]. Most of the eggs produced in the world are sold as whole shell eggs, table eggs to customer. The eggshell is important factor for the consumer in choosing an eggs. Eggs of which shell is clean and non-dirty are primarily preferred by the consumers, and soiled or visually dirty eggs, broken and cracked shell eggs are not preferred [20]. However, shell eggs soiled with feces are sold cheaper to consumers, and it might be therefore preferred by some consumers. In the district of Bandirma where the study was conducted, we observed that in most of the grocer shops and open-air markets where egg sold were also sold the shell eggs soiled with feces. In this study, we aimed to determine whether these eggs pose a risk in terms of the presence of foodborne pathogens such as *Salmonella* spp., *Campylobacter* spp., and *Listeria* spp., due to fecal soiled.

MATERIALS AND METHODS

Sample collection: A total of 412 table egg (conventional chicken egg) samples of which shells were soiled with feces were randomly purchased at the time of sale from 16 separate retail locations (10 shops and 6 open-air markets) in Bandirma district where located in the Southern Marmara Region of Turkey. The eggs purchased were in cardboard trays and unpackaged, and none of them had visible cracks. The egg samples were aseptically transported to the laboratory under chilled condition, and stored 4°C until analyzed. Samples were analyzed within 3 h of taken.

Egg samples preparation for bacteria. isolation from egg shell surface and egg content: Four hundred twelve eggs (206 pooled samples of 2 eggs) were prepared for bacteria isolation from the eggshell surface and the egg contents. Briefly, without breaking, each egg samples (two eggs) was added in 100 mL of sterile phosphate buffer saline (PBS) in Whirl-Pak bags and rinsed by shaking for 2 min. Before rinsing, PBS was warmed to 37 °C to facilitate bacterial recovery. Then, the eggs were removed from the PBS and eight swab samples were taken from the eggshell surfaces, and the eggs allowed to dry completely. For the sample preparation from the contents of these eggs (albumen and yolk), the whole surface of the shell was wiped using gauze soaked in 70% ethanol. Afterward, the eggs were opened using a sterile scalpel blade and the egg contents (ca. 100 g, in total) were emptied into a sterile stomacher bag and homogenized in the 400 mL PBS using a stomacher (IUL Instruments, Barcelona, Spain) for 2 minutes. These prepared samples, namely PBS and swabs taken from eggshell surfaces and homeganates taken from egg contents were used in bacterial isolation. All the egg samples were handled using aseptic techniques.

Isolation and identification of *Salmonella* spp., *Listeria* spp. and *Campylobacter* spp.: For *Salmonella* detection, ISO 6579-1:2017 method was used with slight modifications [21]. Briefly, an aliquot of the PBS (25 mL) and the homogenate (25 mL) were added separately to 225 mL of buffered peptone water (BPW, Oxoid CM509) and incubated at 35°C for 18 h. Two swab samples were dipped into 10 mL BPW together, vortexed and incubated at 35°C for 18 h. Following pre-enrichment, 1 mL and 0.1 mL of each the pre-enrichment culture were taken and inoculated seperately into 10 mL of Muller-Kauffmann Tetrathionate-Novobiocin broth (Oxoid, CM1048) and Rappaport-Vassiliadis-Soya broth (Merck 107700), and incubated 37 and 41.5°C for 24 h, respectively. Then, 100 µl inocula from each enrichment culture were streaked in duplicate onto each of two selective agars, Brilliant Green agar (Oxoid, CM0263) and XLD agar (Oxoid, CM0469). Typical *Salmonella* colonies reproduced or not on the selective agar plates were viewed after incubation at 37°C for 24 h. The suspected *Salmonella* colonies were subcultured on Nutrient agar (Oxoid, CM003B) plates and incubated at 37°C for 24 h, and tested for identification by biochemical and agglutination methods according to the Kauffman White scheme [22].

For detection and identification of thermophilic *Campylobacter* spp., an aliquot of the PBS (25 mL) and the homogenate (25 mL) were added separately to 225 mL Preston *Campylobacter* Selective Enrichment Broth (Oxoid CM67, SR48, SR117, SR232) and 225 mL Bolton Selective Enrichment Broth (Oxoid CM983, SR48, SR183), and each one incubated in microaerobic atmosphere at 42°C for 24 h. Two swab samples were dipped into each one of 10 mL both enrichment broth separately, vortexed and incubated at 42°C for 24 h. Then, 100 µl inocula from each enrichment culture were streaked on modified charcoal cefoperazone deoxycholate agar (Oxoid CM0739, SR155). All plates were incubated under microaerophilic conditions at 42°C for 48 h. Gram-negative, small, curved, catalase- and oxidase-positive bacilli were presumed to be *Campylobacter* spp. Identification to species level was carried out according to its ability to hydrolyse sodium hippurate and indoxyl acetate, H_2S production in triple sugar iron agar, and susceptibility to cephalothin [23,24].

For isolation and identification of *Listeria* spp., an aliquot of the PBS (25 mL) and the homogenate (25 mL) were added separately to 225 mL *Listeria* enrichment broth (LEB, Oxoid, CM862, SR141) and incubated at 30°C for 48 h. Two swab samples were dipped into 10 mL LEB together, vortexed and incubated at 30°C for 48 h. Then, 100 µl inocula from each enrichment culture were streaked on each of three selective agars, Oxford agar (Oxoid CM856), Palcam agar (Oxoid CM877) and Brillance *Listeria* agar (Oxoid CM1080). All selective plates were incubated at 35°C for 48 h. At least five colonies resembling *Listeria* from each of three selective plates were transferred on Tryptic Soy agar (Oxoid CM131) with Yeast extract (Oxoid L21), and incubated at 37°C for 24 h. All the colonies were confirmed to the standard identification and biochemical tests including Gram staining, catalase activity, oxidase reaction, H_2S production, indole test, urease activity, motility in SIM medium at 25°C, β-haemolysis on blood agar, nitrate reduction, methyl-red-Voges Proskauer test, CAMP test with control strains of *Staphylococcus aureus* and *Rhodococcus equi,* and acide production from rhamnose, xylose, mannitol and α-methyl-D-mannopyranoside [25].

RESULTS

As a result of bacteriological analysis, *Salmonella* spp., *Campylobacter* spp. and *Listeria* spp. were detected on eggshell surface samples, at rates of 1.45% (3/206), 0.97% (2/206) and 2.42% (5/206), respectively. However, these pathogens were not isolated from the egg content samples. All *Salmonella* isolates were isolated from PBS samples prepared, ie from eggshell surface wash. However, all *Campylobacter* and *Listeria* isolates were obtained from swab samples prepared eggshell surface. Three *Salmonella* isolates were serotyped as *S*. Infantis. Two *Campylobacter* isolates were detected to be *C. jejuni*. Five *Listeria* isolates were identified as 1 L. *monocytogenes*, 3 L. *innocua* and 1 L. *grayi*. The results are presented in Table 1.

DISCUSSION

The first pathogen that comes to mind in the cases of eggborne diseases is *Salmonella* which may be contaminated to eggshell and/or egg content and has been found to be prevalent in eggs. In previous studies conducted in different countries, the prevalence of *Salmonella* in eggshell and egg content has been reported approximately between 0-83% and 0-15%, respectively. In a study conducted by Mahmud et al. [26] in Bangladesh, the prevalence of *Salmonella* in eggshell and egg content was found to be 83% and 3%, respectively. These rates were reported as 38.88% and 15.07% in Pakistan [27], 3.8% and 7.6% in Trinidad [28], 8.8% and 1.5% in Nigeria [29], 5.9% and 1.8% in South India [30], respectively. These results are higher than our results (1.45% and 0%, respectively). In the studies conducted by Gole et al. [6] in Australia, by Yenilmez and Bulancak [31] in Turkey, by Messelhäusser et al. [32] in Germany, by Jones and Musgrove [33] in USA, by Sasaki et al. [34] in Japan and by Murchie et al. [35] in Ireland, *Salmonella* spp. was isolated from 4.51%, 2%, 1.1%, 1.1%, 0.25% and 0.04% of eggshell samples, respectively but not for egg content samples. These results are in accordance with our results. However, some studies in different countries have reported that *Salmonella* spp. was not isolated from eggshell and egg content [20,36,37]. All these results shows that the prevalence of *Salmonella* on eggshell was higher than that found in egg contents. Eggs can be infected by *Salmonella* via two major ways; vertically, during the formation of an egg in the reproductive tract of hens and horizontally, during transit through the cloaca or after oviposition and fecal contamination of the external surface of the shell, *Salmonella* contaminating the eggshell surface penetrates through the shell membrane. Eggshell contamination with *Salmonella* can be caused by infected hens, and also occured through egg contact with fecal material, and even through in farm egg-packing plants, transportation, storage or during handling [8,27,38,39]. A study performed in commercial layer farms in Korea, *Salmonella* was detected at rates 41.8%, 40.3%, 17.2% and 5.2% in feces, dust, eggshells and egg contents, respectively [40]. In a study conducted by Chemally et al. [41] were declared that 39.3% of the positive flocks had at least one positive eggshell, with a total of 1.05% of eggshells testing positive for *Salmonella*. Arnold et al. [42] concluded that there is a linear relationship between the rate of contamination of egg contents and the prevalence of infected chickens, but a nonlinear relationship between infection prevalence

TABLE 1
Results of bacteriological analysis in retail table egg samples soiled with feces

	Samples (n= 412, pooled to 206 samples)	
	Egg shell surface (n=206)	Egg content (n=206)
Salmonella Infantis	3	-
Campylobacter jejuni	2	-
Listeria monocytogenes	1	-
Listeria innocua	3	-
Listeria grayi	1	-

(-): No isolation

and the rate of eggshell contamination, with eggshell contamination occurring at a much higher rate. *Salmonella* contamination of eggs during the production process is a complicated problem that is affected by a variety of factors including hen housing, flock size, flock age, stress, feed, vaccination, and cleaning routines [6,39,40,43]. Furthermore, Gole et al. [44] reported that fecal contamination with *Salmonella* is the most important factor for the production of *Salmonella*-positive eggshells. In a study by Little et al. [45] on shell eggs used in food service facilities in the United Kingdom, *Salmonella* was detected higher rate in dirty (visibly soiled and/or the presence of fecal matter) eggshells (1.5%) than clean eggshells (0.1%). Therefore, the prevalence of *Salmonella* on the eggshell and in the egg content might vary depending on the investigation of randomly sampled table eggs or on eggs from infected hens. At this point, it's clear that national *Salmonella* control programmes in poultry are necessary to reduce the risk of infected eggs entering the food supply.

Various *Salmonella* serovars can be isolated in table eggs and their occurrence varies greatly between countries [28,30,46]. In current study, only one *Salmonella* serotype, *S*. Infantis, was isolated from eggshell surfaces. *S*. Infantis was the fourth most common serovar of confirmed human salmonellosis cases in the EU / European Economic Area in 2017 [8]. In studies conducted in table eggs in different countries, *S*. Infantis was isolated mainly from eggshells, but also from egg contents [46]. In Australia, a study showed that *S*.Infantis is the most frequently reported serovar from the eggshell wash of eggs collected from layer hen flocks [6]. In Japan, *S*. Infantis was isolated from both eggshells and egg contents [47]. The isolation of *S*. Infantis from the ovaries of commercial laying hens during slaughter [48] suggested that the organism could be transmitted to the egg through transovarian infection and also caused public health concern [49]. However, there is currently insufficient data on this subject. *S*. Enteritidis is considered the serovar to contaminate the egg contents through vertical transmission, while other *Salmonella* serovars are considered generally to contaminate the eggs externally, and found in egg contents by migration through the eggshell and egg membranes [46]. In a experimental study by Cox et al. [49], *S*. Infantis was able to penetrate the eggshell in one day at 25°C and in most cases contaminated the egg yolk; however, penetration was much slower at 4°C and 35°C, used the sterile chicken feces to inoculate the organism onto the egg surface. Chicken feces has been shown to facilitate the penetration of an organism into an egg, simulating a natural process, hence damp, sterilised or fresh chicken feces is employed as the carrier of organisms on the egg surface [49,50]. As a result, although *Salmonella* was not isolated from egg contents in the current study, the likelihood of this organism being present in eggs soiled with feces might be higher.

In current study, *C. jejuni* (0.97%) and *Listeria* spp. (2.42%) including *L. monocytogenes*, *L. innocua* and *L. grayi* were isolated from eggshells surface, but not isolated from any of egg content. In a study conducted by Messelhäusser et al. [32], *Campylobacter* spp. were isolated from 11 (4.1%) eggshell samples, but not for egg yolk samples, and 3 isolates were identified as *C. jejuni* and 8 isolates as *C. coli*. The researchers have also been concluded that *Campylobacter* spp. can be found regularly on the eggshells of table eggs [32]. However, Adesiyun et al. [28] reported that *Campylobacter* spp. were isolated from 2 (1.1%) egg contents of 184 table egg samples but not from any of the eggshell samples, and each of two were identified as *C. coli*. In a study conducted by Sato and Sashihara [51], *Campylobacter* strains were isolated from unpasteurized liquid whole egg and egg yolk samples at frequencies of 27.9% and 36%, respectively while no *Campylobacter* isolates were found in the pasteurized whole liquid egg or unpasteurized liquid egg white, and *C. jejuni* and *C. coli* were detected from 29.5% and 0.5% of the samples, respectively. Apparently *C. jejuni* and *C. coli* are more prevalent in eggs, similar to that in poultry meats [52]. *C. jejuni* is the main *Campylobacter* species responsible for human infections and usually predominant in poultry, subsequently *C. coli* causing human Campylobacteriosis [53]. In a study performed by Jones and Musgrove [33], 0.5% and 21% of the restricted shells eggs samples investigated were found to be positive for *Campylobacter* spp. (1 shell) and *Listeria* spp. (33 shell and 5 content), respectively, and *Listeria* isolates were identified as *L. grayi*, *L. welshimeri* and *L. innocua*. Similarly, in another study, *Listeria* spp. were isolated in 36% of commercially broken raw liquid whole egg samples, and identified as *L. monocytogenes* and *L. innocua* [54]. In these recent studies, the frequently isolated species was *L. innocua* as in our study. *L. innocua* closely related to *L. monocytogenes* and commonly used by the food industry as an indicator to identify environmental conditions allowing the presence, growth, and persistence of the relevant human pathogen *L. monocytogenes*, and also commonly found in chicken products. *L. monocytogenes* is widely recognized as the only species of public health concern [55].

In conclusion, the present study showed that the table eggs soiled with feces are potential reservoir for *Salmonella* spp., *Campylobacter* spp. and *Listeria* spp. These pathogenic species might be cause infections in humans during consumption of the eggs. Externally contaminated eggs always creates a risk in processing phase. Bacteria originating from the surface of eggs could be cross-contaminate the egg content or other food stuffs [52]. Contamination of the egg contents mostly occurs during the breaking of the egg shell [32], and this stuation may be cause the production of ready-to-eat foods with raw or undercooked egg contents, which could be a source of foodborne infections. Moreover, the humans may be exposed to the organisms through contact with the eggs. For this reason, we recommend not selling table eggs soiled with feces directly to the consumer and using them after they have been cracked and pasteurized. Consequently, in the concept of safe food from farm to fork, carrying the control programmes to the points of retail sale of eggs would be beneficial.

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TEMPORAL AND REGIONAL DIFFERENCES AND EMPIRICAL ANALYSIS OF CAUSES OF CORN PRODUCTION COSTS IN CHINA

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ABSTRACT

The temporal and regional differences (TRD) of corn production cost is a hotspot in agriculture. In this paper, the TRD of corn production costs across the country and various regions from 2008 to 2018 is presented based on GIS exploratory spatial data analysis method (ESDA). Simultaneously, a spatial panel model is established to conduct an empirical analysis of the main factors, which affect corn production costs. The results show that the production cost of Chinese three major corn producing areas is increasing year by year. Moreover, the cost of corn production has significant spatial differences, and generally shows a trend of gradual increase from the east to the west. Among them, the southern mountain and hilly corn area has the highest production cost, and the Huang-huai-hai summer corn area has the lowest production cost; the Huang-huai-hai summer corn area has the fastest growth in production costs, while the northern spring corn area has the slowest growth. In addition, the cost of corn production in various regions is spatially correlated, and factors such as the scale of land management, labor structure, degree of mechanization, and socioeconomic conditions have a significant impact on the cost of corn production in China. Therefore, optimizing four kinds of process, which include rural surplus labor transfer, agricultural mechanization development according to local conditions, farmers income increase, land scale management, is conducive to reducing the cost of corn production in China.

KEYWORDS:
Cost of corn production, temporal and regional differences, causes, spatial autocorrelation analysis, spatial panel model

INTRODUCTION

The development of grain production is not only related to the economic benefit of Chinese farmers, but also related to the country's grain security. There are not only opportunities but also severe challenges in grain production after Chinese accession to the WTO. In 2018, Chinese grain stocks continued to rise because Chinese grain supply and demand gap was less than 45 million tons and Chinese grain imports exceeded 115 million tons. The above situations constitute the strange phenomenon of Chinese grain "three-quantity increase" [1-2].The appearance of the strange phenomenon can be attributed to the ceiling effect of Chinese agricultural product prices and the squeeze effect of rising cost floors [3]. China is the second largest corn producer and consumer in the world after the United States. Corn production has continuously exceeded rice output since 2012, ranking first in Chinese grain output. In 2018, Chinese grain output was 658 million tons, of which corn was 257 million tons, accounting for 39.09%. It can be seen that corn occupies an important position in Chinses food security, and the level of costs of corn production has a significant impact on the international competitiveness of Chinese corn. According to natural resource endowments and production conditions, the "Maize Advantage Regional Layout Plan" divides Chinese corn planting areas into the northern spring corn area, the Huang-huai-hai summer corn area, and Southern hilly corn area. The corn planting area in the three major regions accounted for 47.74%, 37.67%, and 10.24% of total planting area. In these three regions, costs of corn production are too high and benefits are too low [4-5], which seriously affects the international competitiveness of Chinese corn production. Therefore, studying the temporal and spatial differences and causes of production costs of corn has important theoretical and practical significance for improving the efficiency of corn production, reducing the cost of corn production in various regions of China to the greatest extent, improving the international competitiveness of Chinese corn, and increasing the income of grain farmers. Previous studies on the cost of corn production in China, or a comparative advantage analysis of corn production in China [6-8], or a small-scale study on costs of corn production in a certain province or region [9-12], or Research on efficiency of corn production [13-15], there are few studies on the temporal and spatial differences of costs of corn production. In terms of analysis of influencing factors, most scholars are limited to the theoretical discussion [16-22], and a few scholars have conducted quantitative research [16-17], but usually assume that the regional variables are independent of each other, and seldom pay attention to spatial dependence.

This article uses statistical analysis and quantitative analysis methods to systematically analyze the production costs of corn in various regions in China, and conduct a comprehensive spatial quantitative analysis of causes that lead to the temporal and spatial differences of production costs of corn. Above study has important reference value for guiding the layout of corn production in the country and in various regions, maximizing the use of limited land resources and natural resources, and improving the comparative advantages and market competitiveness of corn production in various regions.

MATERIALS AND METHODS

Data Sources. This paper uses production cost of corn as the analysis index. In order to ensure time series consistency, comparability and availability of data, this study selects 2008-2018 years as the analysis period. The data comes from the "Compilation of National Agricultural Product Cost and Benefit Information" (2009-2019), "China Statistical Yearbook", "China Agricultural Statistical Yearbook", "China Agricultural Mechanization Statistical Yearbook" and provincial "Statistical Yearbooks".

From the perspective of factor classification, the total cost of food production can be divided into production cost and land cost [21-23]. Production cost is the cost of various funds (including material and cash) and labor invested in the production of the product in the direct production process. It reflects the consumption of various resources other than land for the production of the product. It is mainly composed of material and Service costs and labor costs. Material and service costs refer to the costs of various agricultural production materials consumed in the direct production process, the expenditures for purchasing various services, and other physical or cash expenditures related to production. Labor cost refers to the labor cost invested in the process of food production, which mainly includes two parts: family labor discount and labor cost. Land cost refers to the cost of land input into production as a production factor, including the rent of circulation land and the discounted rent of self-employed land. The production cost of corn studied in this paper refers to the total cost of corn production, which is divided into three parts: material and service costs, labor costs and land costs.

Research methods. This study uses Excel and ArcGIS 10.2 which is processing tool of spatial analysis, combined with global spatial autocorrelation and local spatial autocorrelation methods to analyze the temporal and regional differences of production costs of corn, and build a spatial panel model to study the factors affecting production costs of corn.

Global spatial autocorrelation method. The global spatial autocorrelation analysis is based on the macro level. Moran's I is used to compare the average production cost of corn in the country with the cost of each province to obtain the correlation of the entire study area. The calculation formulas are (Eq. 1-Eq. 2):

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right)}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \quad (1)$$

$$S^2 = \frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2, \quad \bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (2)$$

In the formulas, n is sum of all research objects and are the values of the corn production cost value x at the adjacent paired space points. Is the average of all production costs of corn. Wij is the spatial weight matrix expression. Value range of Moran's I is [-1,1].If I>0, it means a positive spatial correlation, and objects with similar attributes gather together; if I<0, it means a negative spatial correlation, that is Space adjacent units do not have similar properties; when I=0, it means random distribution and there is no spatial autocorrelation.

After calculating the Moran's I index, the P value of the standardized statistic Z value is generally used to test whether there is spatial autocorrelation in the production cost of the regional unit. The calculation formula is: (Eq. 3)

$$Z = \frac{I - E(I)}{\sqrt{Var(I)}}$$

In the formula, E(I) is the digital expected value and Var(I) is the coefficient of variation. If Z<1.96 or Z > 1.96, the global spatial autocorrelation between regions is significant. If P is less than the given significance level (this article takes 5%), then the global spatial autocorrelation between regions is significant.

Local spatial autocorrelation method. The local autocorrelation analysis is to analyze the production cost of the main corn planting areas in the country from the micro level. Local Moran's I is used to judge whether there is a spatial agglomeration or diffusion state in each province and its surrounding neighbors which makes up for the lack of global spatial autocorrelation that cannot reflect the spatial and temporal differentiation of the spatial correlation pattern of corn production costs within the region.

The calculation formula is:

$$I_i \qquad \sum_{j \neq i}^{n} W_{ij} Z_j \qquad Z$$

In the formula, Xi and Xj are the deviations of the observed value of Zi and Zj from the mean value. Wij is the normalized spatial weight matrix, asymmetric.

When the local Moran's I>0 and the significance test (P value test) is passed, it means that there is a local positive spatial correlation and the attribute values of the surrounding spatial units are similar; when the local Moran's I<0 and the significance test is passed, it Indicates that there is a local negative spatial correlation and the attribute values of surrounding spatial units are different. There are four types of local spatial agglomeration: 1) HH (high-high) cost zone which mainly refers to the relatively high cost of corn production in the province itself and the surrounding areas. In this area, the degree of spatial difference is small; 2) HL (high-low) Cost zone which refers to high corn production cost of the province itself and low corn production cost of the surrounding area. In this area, the degree of spatial difference is large; 3) LH (low-high) cost zone which refers to low corn production cost of the province itself and high corn production cost of the surrounding area. In this area, the degree of spatial difference is large; 4) LL (low-low) cost zone which mainly refers to the relatively low cost of corn production in the province itself and the surrounding areas. In this area, the degree of spatial difference is small.

Empirical Model of Influencing Factors. Corn production is a complex system, not only directly affected by production factors such as land and labor, but also closely related to technical level and socioeconomic conditions [16-22]. In order to explore the factors affecting production cost of corn(using the constant price in 2008), this paper selects the average sown area of labor from the level of land management scale [28-29], the proportion of non-agricultural population at the labor structure level [30], the comprehensive mechanization level of corn cultivation and harvest at the level of mechanization [31], per capita annual income of farmers (using the constant price in 2008)and proportion of agricultural output value at the level of socio-economic conditions for analysis (Table 1).

If the production cost of corn has spatial autocorrelation characteristics in the study area, there will be setting deviations to use ordinary panel regression model. Therefore, this paper uses a spatial measurement model for empirical analysis. According to research needs, two basic spatial panel models are constructed [32-33]: spatial lag panel model (SLPDM) and spatial error panel model (SEPDM). The formulas are as follow: (Eq 5, 6)

$$CP_{it}=\alpha_0+\alpha_1 lnland_{it}+\alpha_2 citizen_{it}+\alpha_3 machine_{it}+\alpha_4 lnagrigdp_{it}+\alpha_5 agripercent_{it}+\lambda\sum_{j=1}^{N} w_{ij}cp_{jt}+\varepsilon_{it} \quad (5$$

$$CP_{it}=\beta_0+\beta_1 lnland_{it}+\beta_2 citizen_{it}+\beta_3 machine_{it}+\beta_4 lnagrigdp_{it}+\beta_5 agripercent_{it}+\rho\sum_{j=1}^{N} w_{ij}cp_{jt}+\varepsilon_{it} \quad (6$$

(5, 6)

TABLE 1
Variable meaning and descriptive statistical analysis

Variable	Variable symbol	Variable meaning	Obs	Mean	Std.Dev.	Min	Max
production cost of corn	*CP*	production cost of corn	231	6.47	0.21	6.02	7.10
The scale of land management	*lnland*	Sown area per labor	231	8.87	0.88	7.12	10.75
Labor structure	*citizen*	Proportion of non-agricultural population	231	0.51	0.09	0.29	0.70
Degree of mechanization	*machine*	Comprehensive Mechanization Level of Corn Cultivation and Harvest	231	0.55	0.27	0.01	1.00
Socio-economic condition	*lnagrigdp*	Per capita annual income of farmers	231	8.62	0.40	7.51	9.40
	agripercen	Proportion of agricultural output value	231	0.12	0.05	0.04	0.28

Note: Except for the number of samples, all other values are the results after taking the logarithm.

In the formulas, represents each area of the cross-section (i=1, 2,..., N); t represents the time series of the study (t=1, 2,..., T); w is the spatial weight matrix. α0, α1 , …, α5 andβ0,β1 ,…,β5 are waiting estimated parameter. ε is a random disturbance item that obeys the normal distribution and is independent of each other; λ is the spatial regression coefficient; ρ is the spatial error coefficient. CP represents the production cost of corn; Inland represents the average sown area of labor; Citizen represents the proportion of non-agricultural population; Machine Representing the comprehensive mechanization level of corn cultivation and harvesting; Inagrigdp represents farmers' per capita annual income; Agripercent represents the proportion of agricultural output value.

RESULTS AND DISCUSSION

Time series characteristics of production costs of corn. According to the "Maize Dominant Regional Layout Plan", Chinese 20 main corn producing areas are divided into the northern spring corn area, the Huang-huai-hai summer corn area, and the southern mountain and hilly corn area. Among them, the northern spring corn area includes Inner Mongolia, Liaoning, Jilin, Heilongjiang, Ningxia, Gansu and Xinjiang; the Huang-huai-hai summer corn area includes Hebei, Shanxi, Jiangsu, Anhui, Shandong, Henan and Shaanxi; the southern mountain and hilly corn growing area includes Hubei, Guangxi, Chongqing, Sichuan, Guizhou and Yunnan. Plot the change graph in production costs of corn in China and the three major corn producing regions from 2008 to 2018 (Figure 1).

The results show: from 2008 to 2018, the overall production cost of corn in China showed a trend of rapid growth first and then slow growth. The average cost of production corn in China in 2018 was 1044.82 yuan/mu, which was twice the cost of corn production in 2008, with an average annual growth rate of 7.18%. The change trend of corn production costs in the three major corn producing areas is basically the same as that of the whole country, showing an upward trend year by year. The cost of Huang-huai-hai summer corn grew fastest, increasing from 470.10 yuan/mu in 2008 to 1023.87 yuan/mu in 2018, an average annual increase of 8.10%, followed by the cost of southern mountain and hilly corn area, which increased from 592.42 yuan/mu in 2008 to 1268.90 yuan/mu in 2018, an average annual growth rate of 7.90%. The northern spring corn area grew relatively slowly, increasing from 601.63 yuan/mu in 2008 to 1142.50 yuan/mu in 2018, an average annual increase of 6.63%. The reason for the rapid increase in the cost of summer corn in Huang-huai-hai is that the initial level of corn production costs is relatively low. The main reason for the slower cost growth in the northern spring corn area is the rapid development of agricultural mechanization in this area, the increasingly significant role of machinery substitution, and a relatively small proportion of labor costs (Table 2). Among the three main producing areas, only the northern spring corn area has a lower labor cost than the national average.

The cost of corn production in my country is showing an upward trend year by year. The reason is that the cost of corn production is most significantly affected by labor costs, and the elastic coefficient of regional cost to labor input exceeds 0.5 [34-35]. In the past ten years, labor prices have soared. From 2008 to 2018, Chinese corn labor price increased from 21.60 yuan/day to 84.89 yuan/day, an increase of nearly three times, which in turn caused the increase of corn production costs.

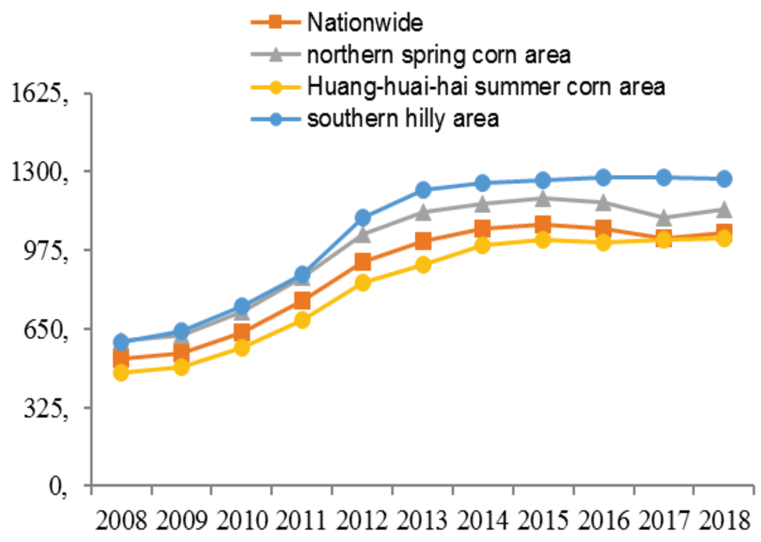

FIGURE 1
Corn production cost of china and three major corn producing areas from 2008 to 2018

TABLE 2
The cost value and proportion of each component of the input of production factors

Region	2008					2018				
	Labor cost	Seed cost	Fertilizer cost	Pesticide cost	Mechanical operation costs	Labor cost	Seed cost	Fertilizer cost	Pesticide cost	Mechanical operation costs
nation	42.11%	6.78%	28.69%	2.28%	15.02%	53.04%	6.82%	16.83%	2.09%	17.02%
Northern spring corn area	39.90%	5.93%	27.53%	1.80%	16.96%	49.43%	7.15%	16.72%	1.74%	19.50%
Huang-Huai-hai summer corn area	42.97%	7.23%	29.49%	2.61%	14.01%	54.14%	6.25%	16.57%	2.27%	16.74%
Southern hilly corn area	55.52%	6.06%	21.60%	1.51%	8.24%	70.54%	5.41%	11.66%	1.23%	6.88%

FIGURE 2
Corn production costs in various regions of China in 2008、2013 and 2018

Characteristics of Spatial Differences in Corn Production Costs. Using ArcGIS software to spatially display the corn production costs of 20 major corn-producing provinces in 2008, 2013, and 2018 (Figure 2), and analyze the characteristics of regional differences in corn production costs. The results show: the cost of corn production generally shows a trend of gradually increasing from east to west. The production cost of the southern mountain and hilly corn area> the production cost of the northern spring corn area> the production cost of the Huang-huai-hai summer corn area. The main reason why the production cost of corn in the southern mountainous and hilly region is higher than that in other regions is natural geographical factors [36]. The relationship between man and land in the southern mountainous and hilly region is tense. Mountains and hills in Yunnan, Guizhou, Sichuan, Guangxi and other places account for more than 90% of area, which is not conducive to the development of mechanical operations, and the labor input level is much higher than other regions.

From the provincial level, ① Quite high cost: the production costs of corn in Gansu Province have exceeded the national average for 11 consecutive years, ranking first in the cost of corn production in all provinces in China. In 2018, Gansu's corn production cost reached 1,850.27 yuan/mu, which was nearly 1.77 times higher than national corn production cost. ② Relative medium cost: In 2008, the regions with medium production cost included 9 provinces, such as Yunnan, Guangxi, Jilin and so on, accounting for 45% of the number of provinces studied. In 2018, the medium cost regions included 8 provinces, such as Yunnan, Guizhou, Ningxia, Chongqing and so on, accounted for 40%. ③ Relative low cost: In 2008, 10 provinces had lower corn production costs, such as Heilongjiang, Henan, Anhui, Jiangsu and so on, accounting for 50% of the studied area. In 2018, 11 provinces, including Anhui, Heilongjiang, Inner Mongolia, Liaoning and so on, had low cost, accounting for 55%.On the whole, among the 20 major corn-producing provinces from 2008 to 2018, the relatively medium-cost regions decreased, and the low-cost regions expanded, showing an overall improvement trend.

TABLE 3
Global Moran's I index of maize production cost of china from 2008 to 2018

year	Global Moran's I	Z value	P value
2008	0.391	35.233	0.001
2009	0.419	37.466	0.001
2010	0.417	3.748	0.001
2011	0.426	38.189	0.001
2012	0.401	3.623	0.001
2013	0.402	36.354	0.001
2014	0.403	36.427	0.001
2015	0.406	36.776	0.001
2016	0.402	36.475	0.001
2017	0.398	35.946	0.001
2018	0.405	36.624	0.001

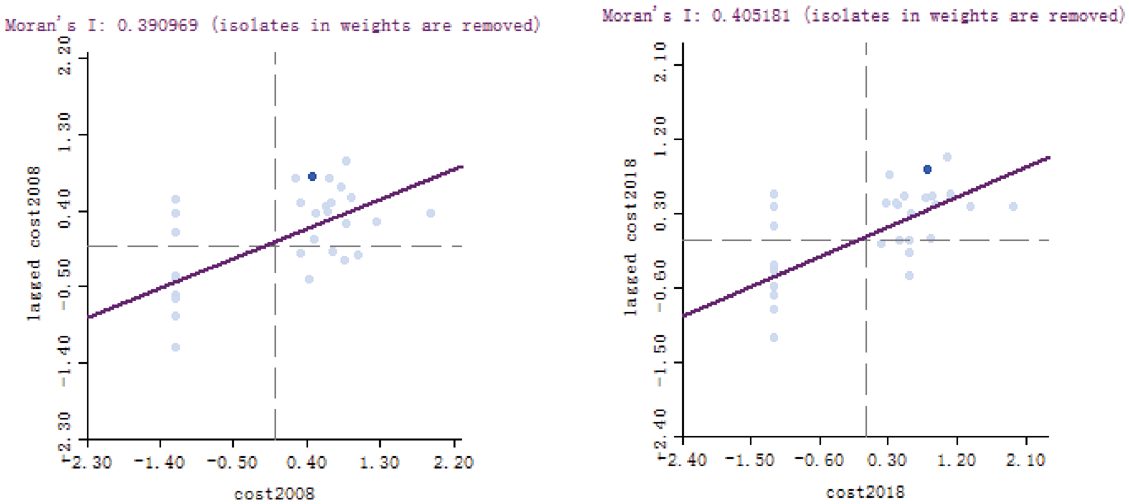

FIGURE 3
Moran scatter plots of Corn Production Cost in various regions of China in 2008 and 2018

Global spatial autocorrelation analysis of corn production cost. With the help of GeoDa software, the global Moran's I index and its corresponding Z and P values (Table 3) of corn production costs in Chinese 20 main producing provinces from 2008 to 2018 were obtained to explore the overall features of corn production costs in China: The global Moran's I index is greater than 0, but less than 0.5, indicating that the cost of corn production is globally spatially autocorrelated, and the cost of corn production in neighboring provinces has similar attributes. At the same time, the global Moran's I indexs from 2008 to 2018 are around 0.4, indicating that the spatial characteristics of Chinese corn production costs are relatively stable. From the test results, the P values from 2008 to 2018 are less than 5% and the corresponding normal statistic Z values (Z-Scores) are larger than the critical value (1.96) of the normal distribution function when the probability is 0.05. It has passed the significance test and will be further analyzed through local autocorrelation.

Local spatial autocorrelation analysis of corn production cost. In order to further explore the aggregation characteristics of China's corn production costs at the provincial level, this paper conducts local spatial autocorrelation analysis and draws local Moran's I scatter plots and LISA cluster maps in 2008 and 2018. From the scatter plots (Figure 3), it can be seen that the spatial agglomeration of corn production costs has not changed significantly in 11 years. Therefore, it is necessary to further study the spatial agglomeration of corn production costs in various regions in a local area according to the LISA analysis (LISA is a measure of the correlation and significance index between a certain spatial unit and surrounding units). It can be seen from LISA aggregation map (Figure 4) that during 11 years, most of the study areas had no obvious spatial correlation (gray areas). A small number of areas showed "HH" aggregation characteristics (red areas), and the "HH" aggregation areas were adjacent to Gansu Province, which has the highest corn production cost for 11 consecutive years, indicating that the spatial dependence and agglomeration characteristics of high-cost areas are relatively stable. Among the research areas, the provinces of the "L-L" type in 2008 were Shandong and Henan, and in 2018 it was Jilin Province.

The lower-cost areas changed from the Huang-huai-hai corn area to the northern area, indicating that due to the difference in development speed, low-cost areas have changed agglomeration characteristics.

Empirical analysis of factors affecting corn production costs. From the above analysis, it can be seen that the cost of corn production has significant geographic spatial relevance. Therefore, this paper uses a spatial measurement model to conduct an empirical analysis of the factors affecting the cost of corn production in china from 2008 to 2018. Use LMlag (Robust LMlag) and LMerr (Robust LMerr) to determine which model is more appropriate. Table 4 shows that the test values of LMlag, Robust LMlag and Lmerr are all significant at the 1% level, while the test value of Robust LMerr is not statistically significant, which shows that SLPDM is better than SEPDM. The spatial Hausman test is significant at the 1% level, indicating that the spatial panel fixed effects model is more suitable than the spatial random effects model. Since the LogL value of the time fixed effects model is the largest, and the R2 (=0.1721) value is also the largest, the model fitting effect is the best. Therefore, this paper uses the time fixed effects model of the spatial lag panel model to explain the main factors affecting corn production costs. In order to observe the impacts of various

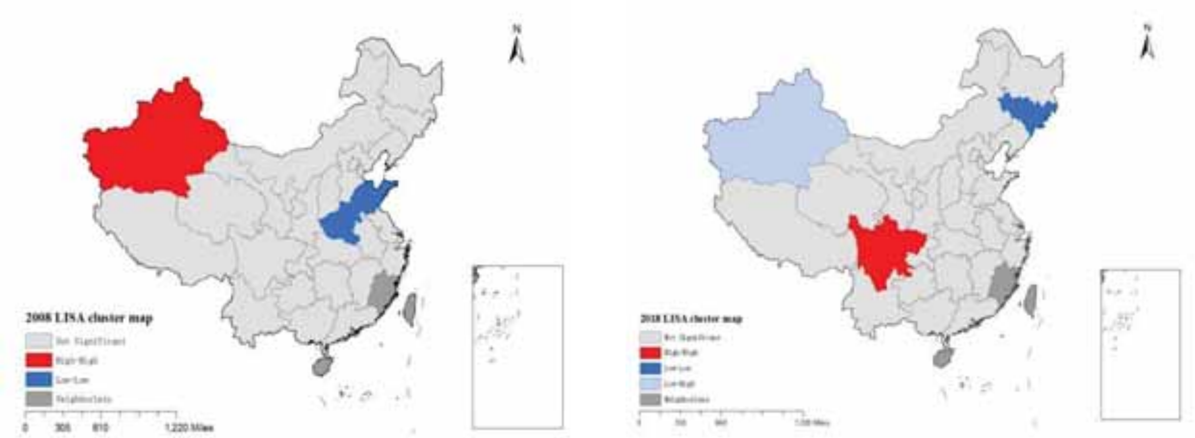

FIGURE 4
LISA cluster maps of Corn Production Cost in various regions of China in 2008 and 2018

TABLE 4
Model statistical test results

Inspection method	Observations	Statistics	P value
LMlag	220	68.984	0.000
Robust LMLag	220	9.988	0.002
LMerr	220	60.602	0.000
Robust LMerr	220	1.607	0.205
Hausman Test	220	88.300	0.000

TABLE 5
Empirical results of factors affecting corn production cost

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5
lnland	0.0126***	0.0069***	0.0709***	0.0680***	0.0794***
	(0.0137)	(0.0136)	(0.0158)	(0.0159)	(0.0169)
	[0.0173]	[0.095]	[0.0972]	[0.0932]	[0.1089]
citizen_		-0.7981***	-0.3857**	-0.4977***	-0.8744***
		(0.1606)	(0.1605)	(0.1892)	(0.2721)
		[-0.0629]	[-0.0304]	[-0.0392]	[-0.0689]
machine_1			-0.3893***	-0.4063***	-0.4123***
			(0.0592)	(0.0610)	(0.0608)
			[-0.0331]	[-0.0345]	[-0.0351]
lnagrigdp				-0.0504**	-0.1169**
				(0.0452)	(0.0569)
				[-0.0672]	[-0.1558]
agripercent_					-0.7081
					(0.3684)
					[-0.0131]
LogL	714.956	833.847	1.030.155	1.036.225	1.055.114
R-squared	0.0035	0.1193	0.2856	0.2916	0.3227
Number of obs	220	220	220	220	220
Model setting	SLPDM	SLPDM	SLPDM	SLPDM	SLPDM

Note: Standard deviation in parentheses; *** means p<0.01, ** means p<0.05, * means p<0.1.

influencing factors on the cost of corn production, this paper estimates the model parameters (model 1-model 4) by gradually adding independent variables on the basis of controlling the dependent variable, and using Stata 16.0 software to estimate the test results (Table 5).

Model 1 only uses the scale of land management as the basic variable to estimate the parameters. The results show that the impact of the scale of land management on the cost of corn production is positive and significant at the 1% level; Model 2 and Model 3 have introduced labor structure variable and mechanization degree variable respectively, and their parameter estimates are negative, and the parameter estimate of land management scale is still positive, indicating that increase in the proportion of non-agricultural population and the comprehensive mechanization of corn cultivation and harvest have reduced the cost of corn production. Model 4 also introduces the per capita annual income of farmers in the socio-economic conditions, and its estimated value is significantly negative at the 5% level. Model 5 introduces the indicator of the proportion of agricultural output value in the socio-economic conditions, which fails the significance test.

From the estimation results of Model 1 to Model 5, it can be seen that the signs of the variables introduced in the model have not changed significantly, and the only change is the size of the parameter estimate, and the magnitude of the change is not large. This fully shows that considering the existence of spatial effects, the impact of the above factors on corn production costs is real. Judging from the parameter estimation results of Model 5:

(1) The marginal effect of the scale of land management on the cost of corn production is 0.0794, and the coefficient of elasticity is 0.1089, that is, for every 1% increase in sown area per labor, the cost of corn production will increase 0.1089%. Related research pointed out [37-42] that there is a "U-shaped" relationship between crop unit cost and scale, that is, as the scale of land management expands, its effect on the reduction of crop production costs gradually weakens, and when it exceeds a certain limit, it will resulting in increasing in production costs. The calculation results in this paper mean that Chinese land scale development has entered a new era, and simply expanding the scale of land management will increase the cost of corn production. This is mainly due to the fact that most of the northern spring corn areas are in plain areas and the land contiguous rate is high. Coupled with national policy support, rural cooperatives have developed rapidly and the scale of land operations has grown rapidly. However, in recent years, as the scale of operations has increased, it has not been able to effectively control the increase in mechanized service prices and land lease prices, which gradually weakens the advantages of economies of scale, and ultimately makes the impact of the scale of land management in this area on the cost of corn production insignificant [43]; The southern mountainous and hilly area is dominated by hilly terrain. The proportion of arable land is small, and the plots are small, scattered and rugged, which increases the difficulty of land scale. The increase in farmland management scale of farmers is mainly achieved by renting other farmland plots, which will not bring about the expansion of farmland plots, and does not exert a resource saving effect, so the impact on corn production costs is not significant.In the Huang-huai-hai summer corn area, which accounts for 35% of the national corn sown area, land circulation has accelerated in recent years, and the scale of land management has expanded. However, the level of mechanization of corn production is low [13], and the substitution of machinery for manpower is insufficient. Taking into account the increase in land transfer rents and labor costs, the scale of land operations in this area has a significant positive impact on the cost of corn production. On the whole, the above-mentioned main corn producing areas work together to make Chinese land management scale have a positive impact on corn production costs.

However, the above conclusions do not mean that the scale of land management should be reduced. Promoting moderate agricultural management is still the key to saving costs and increasing efficiency [44]. Rather, it shows that the current scale of land production, agricultural technology and other production factors in china are not compatible with each other, and their production potential cannot be fully utilized. Therefore, while promoting a moderate scale of operation, it is necessary to promote the full-process mechanized production of corn, Speed up the selection and breeding of fine varieties suitable for mechanized production, and improve the management capabilities of farmers.

(2) The parameter estimates and elasticity coefficients of the labor structure are -0.8744 and -0.0689, respectively, indicating that increasing the proportion of non-agricultural population will help reduce the cost of corn production. The reality also illustrates it. With the transfer of agricultural labor to the secondary and tertiary industries, the shortage of rural labor and the increase in labor prices have forced the efficiency of agricultural production technology to increase, and agricultural machinery operations have gradually become popular. For example, the comprehensive mechanization level of mechanical farming and harvesting of corn in Heilongjiang Province has reached 95% in 2018, basically achieving all mechanization of the cultivation and harvesting links, greatly reducing the amount of labor input. From the perspective of the composition of corn production costs, labor costs have always accounted for a large proportion [34], so reducing the amount of labor used in agricultural production will help alleviate the pressure of rising corn production costs.

(3) The estimated value of the parameter of the impact of the degree of mechanization on the cost of

corn production is -0.4123, and the coefficient of elasticity is-0.0351, that is, for every 1% increase in the comprehensive mechanization level of corn cultivation and harvest, the average corn production cost will be reduced 0.0351%, which means that the cost can be reduced and production benefit will improve through the promotion of agricultural machinery operations. Related research has also proved it [45-46]. Although Chinese corn mechanization has achieved rapid development, the level of agricultural machinery operations has been greatly improved, and the comprehensive mechanization level of corn cultivation and harvest has increased from 51.78% in 2008 to 88.31% in 2018, but there are still many shortcomings and weak links in the development of agricultural mechanization in China. There is still a big gap from the goal of full mechanization in the whole process, and the degree of refinement of operations is not enough. It can be seen from this that in order to further enhance the economical effect of mechanization on corn production, we should take a long-term perspective, make up for shortcomings, and promote agricultural mechanization while focusing on upgrading.

(4) In the socio-economic conditions, the parameter estimated value of farmers' annual income per capita to corn production cost is 0.1169, and the elasticity coefficient is -0.1558. This means to a certain extent that the higher the income of farmers, the lower the cost of corn production. The reason is that only when the economic situation is good, more funds can be invested in improving production conditions, improving production technology, etc. It matches the technical input and labor input, thereby reducing production costs and improving economic benefits.

In terms of the degree of influence of various factors on the cost of corn production in China, the labor structure and the degree of mechanization have a more obvious impact on the cost of corn production than the scale of land management and socio-economic conditions. It can be seen that in order to alleviate the pressure of rising corn production costs in China, in addition to promoting moderate scale operations of arable land and increasing farmers' income, it is more important to promote the surplus agricultural labor force to specialize in secondary and tertiary industries, and to promote the development of agricultural mechanization in accordance with local conditions.

CONCLUSIONS

(1) From 2008 to 2018, Chinese corn production costs showed a trend of rapid growth first and then slow growth. Among them, the areas with low corn production costs grew the fastest, and the areas with high corn production costs grew at a slower rate.

(2) According to the results of ArcGIS spatial display, the spatial difference of corn production costs is obvious, showing a trend of gradual increase from the east to the west. The provinces with higher corn production costs are mainly concentrated in the southwest corn area, and the provinces with lower production costs are mainly concentrated in the Huang-huai-hai summer corn area.

(3) According to the analysis of spatial autocorrelation, the production cost of corn in china has obvious spatial correlation, and the production costs of neighboring regions influence each other. Factors such as the scale of land management, labor structure, degree of mechanization, and socioeconomic conditions have significant impacts on the cost of corn production in China. Among them, the scale of land management has a significant positive impact on the cost of corn production, while factors such as labor structure, degree of mechanization, and socioeconomic conditions have negative impacts on it. The structure of labor and the degree of mechanization are the most important factors. Different factors have different degrees of influence on corn production costs.

(4) Based on the above research, in order to effectively reduce the cost of corn production in china, the following measures need to be taken: First, transfer surplus rural labor, while improving the quality of agricultural laborers to increase the potential for long-term cost reduction; Second, develop mechanization based on local conditions to reduce manual input to increase farmers' income; Third, promote moderate scale management of arable land, develop large-scale and industrialized agricultural production, and at the same time manage the fragmentation of arable land based on land classification, and strengthen land leveling and farmland infrastructure construction.

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M.Y.: Supervision, conceptualization, writing—review and editing.

M.Y.: Funding acquisition, supervision, conceptualization, writing—review and editing.

J.L.: Writing—review and editing.

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NOTICE

ECONOMIC VALUE OF CHICKPEA PRODUCTION CONSUMPTION AND WORLD TRADE

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ABSTRACT

Chickpea is a valuable crop that offers nutritious and healthy food for a growing global population and it will become much more essential with changing climate. In most countries around the world, nutritionists related to health and food have recently emphasized the nutritional value of chickpea for body health and nutrition. Chickpea ranks second after the beans having a mean annual production of about 12.8 million tonnes with the major production originates from India. In recent years, the cultivated area of chickpea has expanded, reaching an estimated 13.7 million hectares. Since 1961, annual production per unit area has increased at the rate of around 6 kg/ha. Annually, around 2.2 million tonnes of chickpea is available in the world market to accomplish countries' requirements when domestic supply is insufficient to meet demand. Leading exporters include Australia, Russia, India, and Mexico. Chickpea comes in two types: Desi and Kabuli. The Desi type is distinguished by its thin, angular seeds that come in a variety of colors and are spotted sometimes. The type Kabuli is separated by large seeds size, smooth surfaces, and a lighter color. In South Asia, chickpea is commonly used in ‘dal’ and ‘hummus’ and is popular around the world. Chickpea germplasm yield capacity has slowly but steadily increased by the research efforts at ICARDA, ICRISAT, and the conduction of national programs.

KEYWORDS:
Pulses, Chickpea, Production, Area, Yield

INTRODUCTION

Pulses are the dry seeds of Legumes crops, which are edible. The split-grain, whole seed, flour, and dehulled split-grain, are all popular forms of consumption. Pulses are cultivated all over the world. The cowpea, pigeon pea, chickpea, dry pea, common bean, urd bean, mung bean, and lentil are the most important pulses in terms of world production and consumption. Furthermore, minor pulses are also cultivated and consumed in various parts of the world. Although pulses are primarily cultivated for human use, they are also in high demand as livestock feed in developed countries. The most commonly used pulses for animal feed are lupins, dry peas, and faba beans. Pulses are a valuable part of balanced food systems because of their nutritional benefits. However, data on pulses consumption suggests that average per capita consumption is below than recommended level and over the last three decades, it has been relatively stable, about 21 grams per capita in a day. Increased consumption of pulses requires easy access, an economical approach, and awareness of their nutritional value. Pulses are high in nutrients as compared to other cereals, they contain more proteins, dietary fibers, and minerals. Pulses have a very low-fat content as well [6].

The protein content of each pulse grain also varies depending on the variety. [1] found that protein content ranges from 15.8% to 32.1% in peas, common beans have 20.9% to 29.2% protein, 19% to 32% in lentils, 22% to 36% in faba beans, 16% to 28% in chickpeas, 21% to 31% in mung beans, 16% to 31% in cowpeas and 16% to 24% in pigeon peas. Both genetic and environmental factors influence the protein content of pulses. In general, protein, starch, and oil content have a negative relationship. The small seed sizes with low yields are common characteristics of protein-rich pulses varieties. Breeders have had some success in developing high-yielding varieties that retain their protein content over the years (ibid.).

Chickpea (*Cicer arietinum*) is a major leguminous crop that is cultivated for human consumption. It is widely consumed and produced in various regions of the globe (Figure 1). Chickpea is a self-pollinated legume and at early phases of growth, it prefers a cool climate with optimal temperatures varies from 15 to 25 degrees Celsius, and as it matures, it prefers a warmer climate [8]. Chickpea is a source of simply digestible protein, as well as minerals like iron, magnesium, calcium, zinc, and phosphorus. The global development of chickpea has seen a considerable transformation in the recent two decades, following a three-decade period of stagnation. Since the 1990s, chickpea's share of the total cultivated area with pulses and overall production of pulses has steadily increased [6].

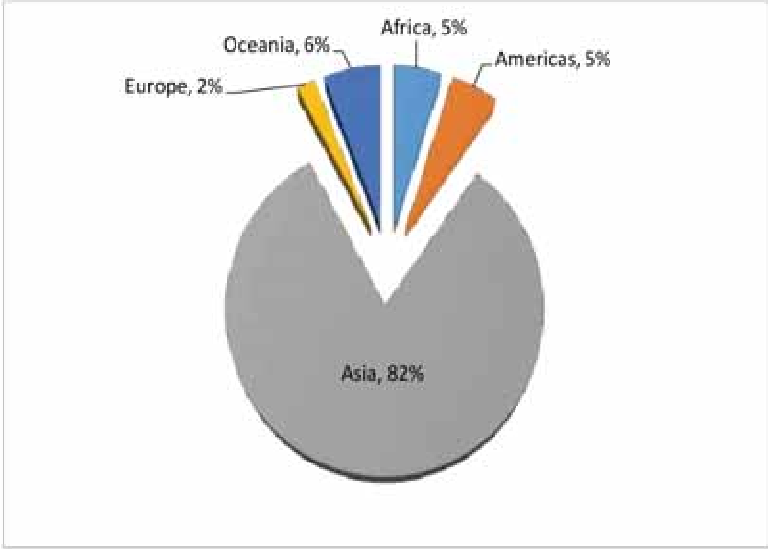

FIGURE 1
Mean annual chickpea production from 2010 to 2019 in different regions of the world
(Source: Food and Agriculture Organization (FAO) (2021))

TABLE 1
Mean annual world production of pulses crops (2010-2019)

Pulses	Production (tonnes)
Beans	27,284,608
Chickpeas	12,844,599
Peas	12,491,202
Cowpeas	7,725,364
Lentils	5,513,954
Broad beans (Faba beans)	4,857,383
Pigeon peas	4,589,374
Other pulses[a]	6,499,299
Total pulses	81,805,783

[a]Other pulses data included lupins, vetches, bambara bean and pulses
Source: Food and Agriculture Organization (FAO) (2021)

In most chickpea-producing countries, there is a significant difference between potential and actual yields. These yield gaps are caused by biotic and abiotic stresses. Abiotic stresses were attributed to about a 6.4 million tonnes annual shortfall in the world production of chickpea, while biotic stresses were attributed to around 4.8 million tonnes. The most common reason for lower yield is drought and heat. Other important abiotic factors affecting chickpea yield globally include freezing at the vegetative process, cooling at the reproductive stage below 10°C, waterlogging, salinity, and nutritional shortages [10].

Among biotic stresses, pest attacks and diseases such as Ascochyta blight, Helicoverpa, and Fusarium wilt also affect chickpea yield and cause severe damage to crops [9]. Chickpea crop has low susceptibility to commonly used herbicides, so herbicides should not be used to control weeds once the crop has emerged. As a result, manual weeding is used in developing countries, while chemical herbicides are only used before sowing or immediately after sowing in developed countries with large farm sizes. Weeds can cause yield loss ranging from 23% to 87% [7, 12]. The biotic stress management plan for chickpea cultivation must include intercropping and crop rotation.

The primary objective of this research is to identify the regional and global trends of chickpea production, consumption, trade, and value since 1961. For the trend estimation, these main regions were included: Latin America and the Caribbean, South and Southeast Asia, Central and East Asia, Sub-Saharan Africa, and the Middle East and North Africa. Developed countries are grouped for comparative analysis under Developed World, which includes, Australia, Europe, and, North and South America.

MATERIALS AND METHODS

Data source: Chickpea demand, trade, and value were studied on a regional, global, and country-level to analyze production patterns and product convenience at national and international export markets. Production and demand data from around the world, as well as from regions and countries, are examined to assess patterns and potential prospects of chickpea and its value in global trade. The data for this study was compiled using the FAOSTAT database, which was provided by the Food and Agriculture Organization of the United Nations (2021) and offers country and worldwide estimates of crop output, consumption, cultivated area, yields, imports, and exports from 1961 to 2019. The information is used to determine global trends in chickpea production, consumption, value, and yields.

RESULTS AND DISCUSSION

Production, productivity and area: Between 2010 and 2019, the contribution of chickpea production in different regions of the world changed significantly (Figure 1). Asia remains a major producer of pulses, accounting for 82% of global chickpea production between 2010 and 2019, with the rest of the world accounting for about 18%. Oceania accounted for 6% of global chickpea production between 2010 and 2019, the Americas and Africa for about 5%, and Europe for about 2%. Global chickpea cultivation, on the other hand, was more limited, with Asia accounting for 82% of total output.

Chickpea is the world's second most important pulse crop, with 12.8 million tonnes produced each year. Chickpea is ranked second after beans (27.3 million tonnes), with a mean annual production of 12.8 million tonnes between 2010 and 2019 (Table 1). Peas and chickpeas produce nearly as much as beans in terms of annual production, demonstrating their overall significance. Chickpeas, peas, and beans contribute around 64% of overall pulses production, while chickpea contributing around 15.7% of total annual production. In terms of cultivated area, chickpea production increased from 11.8 million hectares in 1961 to 13.7 million hectares in 2019 (Figure 2). From 1961 to 2001, chickpea production trends in terms of the cultivated area were relatively stable or slightly declining; however, beginning in the late 1900s, increases in yield began to have an impact on overall production. Production increases began in the early 2000s and have continued until now, mainly after 2004.

Since 1961, the yield of chickpea has been gradually increasing (Figure 3), with an annual rise of more than 6 kg/ha. This progressive trend is most likely the outcome of current research efforts towards improving germplasm and generating higher producing varieties with greater disease resistance and environmental tolerance. Improvements in seed supplies, seed sources, and overall management practices are also important factors. These consistent yield increases may also be attributed to increased productivity in more productive environments. The development of production in developed countries like the United States, Australia, and Canada tends to have a favorable impact on mean yield. Though, since the main part of chickpea production is centered in South Asia, particularly India, increases in that region's output have had a global impact. Chickpea production has increased significantly during the last ten years (Figure 4). Beginning in 2010, the harvested area and the tonnage produced increased steadily until 2019, when world production reached 16 million tonnes from approximately 15 million hectares, which was an all-time high. An increase in output per hectare and harvested area have had a positive impact on overall production.

Chickpea is grown in almost 49 countries, while India producing the most (9.9 million tonnes of total global output). Figure 5. Depicts India's dominance in chickpea production and the relative importance of the next-largest producers. Turkey and Russia, the next two most important producers, contribute 0.63 million tonnes and 0.51 million tonnes of worldwide output, respectively. Myanmar and Pakistan account for 0.50 and 0.45 million tonnes, respectively, while Ethiopia, which has significantly expanded production in recent years, currently contributes nearly 0.44 million tonnes of global production. The United States, Australia, Canada, and Mexico are also important producers.

Chickpea yields have varied greatly among chickpea-producing countries, ranging from a low yield of 370-870 kg/ha in Pakistan and Russia to a relatively high yield of 1,878-2,008 kg/ha in Mexico and Ethiopia (Figure 6). India, the world's largest producer, has maintained an average yield of around 964 kg/ha. Chickpea has a higher yield in Mexico because it has a cool winter climate to cultivate and irrigate the chickpea crop.

TABLE 2
Area harvested (hectares), mean yields (kilograms/hectares), and total production (tonnes) of chickpea in different regions of the world from 2015 to 2019

Region	Country	Area (ha)	Productivity (kg/ha)	Production (tonnes)
Africa	Algeria	29,06	1,051	30,898
	Egypt	1,832	2,312	4,356
	Eritrea	8,776	436	3,825
	Ethiopia	235,084	2,008	471,781
	Malawi	16,243	790	11,824
	Morocco	70,075	737	49,342
	Sudan	12,468	3,121	43,931
	Tunisia	6,396	852	5,494
West Asia	Iran	478,341	452	216,526
	Iraq	83	1,496	118
	Israel	4,302	4,554	18,55
	Jordan	735	4,507	3,178
	Lebanon	2,746	952	2,663
	Kazakhstan	12,258	594	7,254
	Syria	56,517	769	42,334
	Turkey	426,694	1,244	529
	Yemen	19,212	2,287	44,052
South Asia	India	9,276,724	964	9,016,948
	Bangladesh	5,782	1,029	5,92
	Myanmar	374,801	1,438	538,339
	Pakistan	954,568	370	353,011
	Nepal	9,725	1,094	10,647
Asia	China	2,788	5,305	14,798
	Uzbekistan	3,643	2,42	8,851
Europe	Greece	9,352	1,555	14,572
	Italy	15,197	1,573	24,21
	Portugal	1,817	838	1,521
	Russia	546,497	871	466,295
	Spain	41,144	974	40,422
North America	Canada	96,68	1,704	163,42
	Mexico	107,078	1,879	200,591
	USA	193,002	1,604	308,906
South America	Argentina	64,326	1,969	125,957
	Chile	523	695	337
Australia		675,705	1,172	872,619
World (total)		13,710,923	990	13,610,686

Source: Food and Agriculture Organization (FAO) (2021)

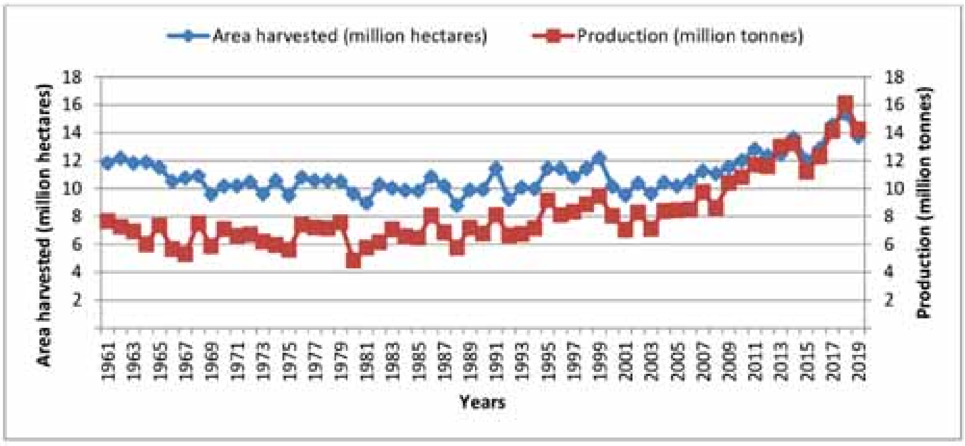

FIGURE 2
Chickpea worldwide, area harvested (million hectares) and production (million tonnes) from 1961 to 2019
(Source: Food and Agriculture Organization (FAO) (2021))

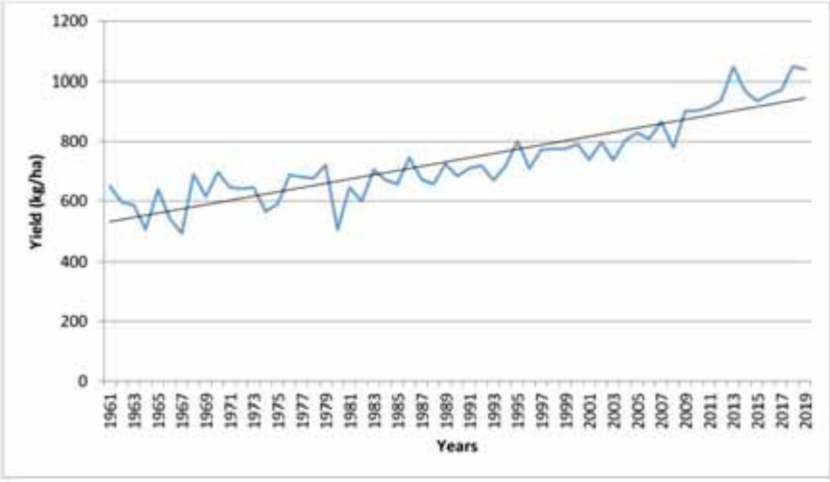

FIGURE 3
Annual trend line of chickpea yield (kg/ha) from 1961 to 2019
(Source: Food and Agriculture Organization (FAO) (2021))

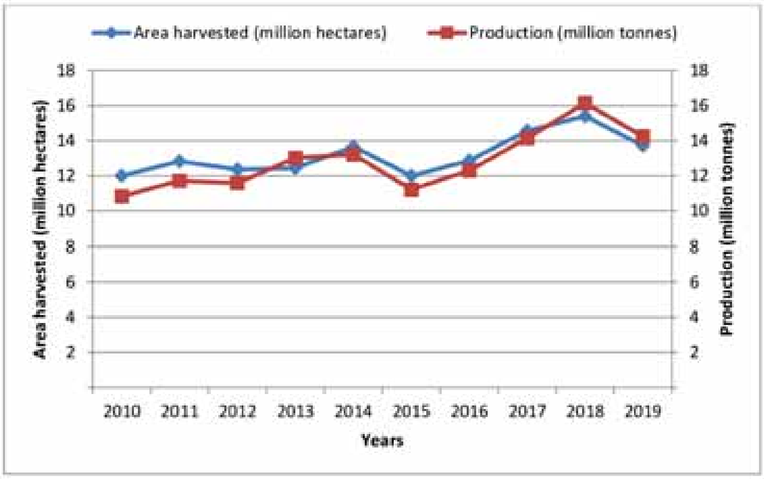

FIGURE 4
Chickpea worldwide, area harvested (million hectares), and production (million tonnes) from 2010 to 2019
(Source: Food and Agriculture Organization (FAO) (2021))

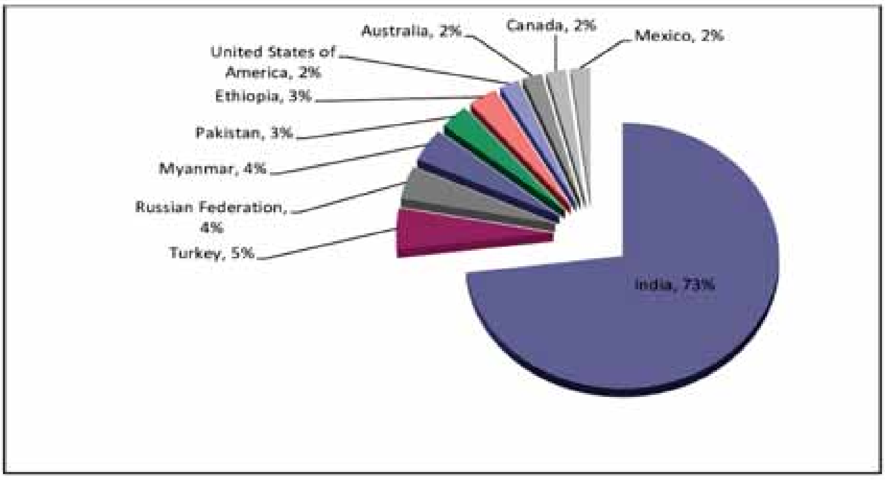

FIGURE 5
Top ten leading chickpea producing countries over the world
(Source: Food and Agriculture Organization (FAO) (2021))

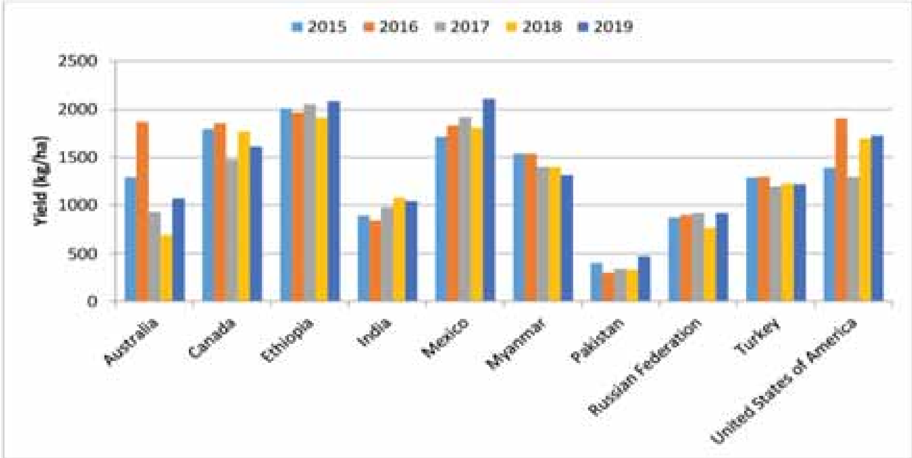

FIGURE 6

Mean yield (kg/ha) of top ten leading chickpea producing countries from 2015 to 2019

(Source: Food and Agriculture Organization (FAO) (2021))

Table 2 shows the overall harvested area, productivity, and production of chickpea in important regions of the world. Ethiopia has emerged as an African leading producer, while West Asia's output is dominated by Iran and Turkey. In Europe, Russia and Spain are the two most important producers. In North America, the United States is the most populous nation, followed by Mexico and Canada. The majority of this output is destined for export; however domestic demand, which now accounts for over 65% of overall output, has been created by the increase of 'hummus' as a common value-added item in the United States. Argentina has emerged as a major producer in South America. Australia has emerged as the main chickpea producer, with the majority of its output going to South Asia to fulfill the demand for chickpea in India and Pakistan (Figure 7).

Contribution of chickpea exports and trade: A large amount of chickpea (estimated at 2.2 million tonnes) has entered the world trade because consuming countries have been unable to meet demand through domestic production. Australia almost covers half of the world's export demand from 2015 to 2019, supplying approximately 1,049,267 tonnes to the market annually [2]. From 2015 to 2019, the average value of exports was $705 million (US$). Though India is the world's largest importer, producer, and a significant exporter of chickpea, coming in third behind Australia and Russia. Mexico is the fourth-largest exporter, with high-quality, large-seeded Kabuli varieties exported to more than 50 countries throughout the world, with Turkey, Algeria, and Spain being the most valuable consumers. Turkey is also a major exporter, exporting about 79,738 tonnes per year, most of which goes to Saudi Arabia, Jordan, and Iraq (Table 3).

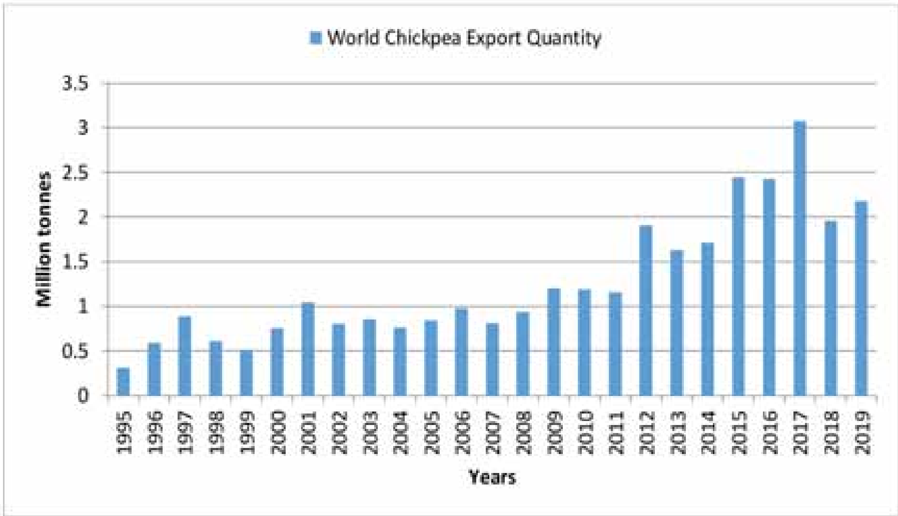

FIGURE 7

Chickpea export quantity from 1995 to 2019 over the world

(Source: Food and Agriculture Organization (FAO) (2021))

TABLE 3
Annual exports of major chickpea exporting countries from 2015 to 2019

Country	Exports (tonnes)
Australia	1,049,267
Russia	263,43
India	155,265
Mexico	135,131
Canada	124,111
Argentina	120,302
USA	119,385
Turkey	79,738
Ethiopia	53,078

Source: Food and Agriculture Organization (FAO) (2021)

TABLE 4
Mean imports of chickpea from 2015 to 2019 in major chickpea producing countries

Country	Imports (tonnes)
Egypt	1,151,598
India	737,278
Pakistan	318,106
Bangladesh	226,809
United Arab Emirates	126,675
Turkey	73,144
Algeria	72,223
Iran	63,761
Saudi Arabia	59,94
USA	55,209
Spain	48,766
Jordan	34,102
Iraq	33,865
Sri Lanka	25,934
Portugal	19,984
Lebanon	15,003
Syria	12,043
France	8,518
Oman	7,874
Libya	7,316
Greece	3,737

Source: Food and Agriculture Organization (FAO) (2021)

Consumption and demand: Chickpea is categorized into two different types. The most popular type is "Desi" which has small seeds and their color vary from light tan to black and contains a variety of markings, including anthocyanin pigmentation. Seed coats are thick despite their small size and have yellow cotyledons. To make "dal" the seeds are sometimes decorticated (removed seed coat) and with broken cotyledons. 'Dal' is a prominent soup ingredient in South Asia, and it can be produced from several pulses crops. The " Kabuli" variety, which is less common, is distinguished by its large seeds, which can reach up to 22 mm in diameter or greater. Kabuli seed coats are light tan and very small, with no pigment. This type is preferred by most markets outside of South Asia, which is likely because of its ease of production and lower cost. The Desi variety dominates chickpea production worldwide, accounting for 80% of overall production, with Kabuli variations accounting for the remaining 20% (Table 4) [5].

Chickpea uses: Protein deficiency has been linked to cognitive, stunting, and wasting deficits in children [3-4, 11]. In adults, protein is required for muscles growth as well as cell repairing and replacement. Pulses have around twice as much protein as wheat and three times as much protein as rice. Chickpea has the highest protein content of the major pulses, ranging from 20.8 to 21.2 grams per 100 grams [6].

Chickpea is rich in minerals and essential B vitamins and includes approximately 60% to 65% carbohydrates and 6% fat. Desi and Kabuli types have a wide range of uses. They can be boiled, roasted, dehulled to make 'Dal', eaten raw, or processed into flour for baking. 'Dal' is a healthy pulse crop that is made primarily from desi varieties and in most parts of South Asia, it's served with rice. Pulses amino acids, especially those including sulfur amino acids, are well known for compensating for those lacking in cereals (Table 5) [5].

CONCLUSIONS

Pulses have seen significant growth in productivity, trade, and consumption over the past fifteen years. This study examines the growth and consumption patterns of chickpeas in various parts of the world, as well as the role, chickpea can play in human nutrition. It discusses how trade is becoming increasingly relevant in the global economy of chickpeas, as well as an overview of changing trade trends. In the period 2010-2019, chickpea accounted for around 15.7% of global pulses production. Chickpea production has increased dramatically over the last fifteen years, according to global trends. This was due to the production of improved chickpea varieties that indicates more yield, less duration, heat-resistance, and adaptability to common chickpea diseases. Because of the development of such varieties, chickpea cultivation is now possible in places of the world where it was previously not available. Chickpea production has accelerated due to the introduction of different varieties and advanced agriculture techniques in both traditional chickpea producing countries such as India and emerging chickpea producing countries such as Turkey, Russia, Myanmar, and Pakistan.

Apart from technical problems, there are some economic and policy concerns that must be addressed for chickpea development to expand further. Extension work is required in countries with smallholder agriculture to provide farmers with information on advance agronomic approaches,

TABLE 5
Leading countries of chickpea production in 2019 and their gross production value ($)

Rank	Country	Production (tonnes)	Gross Production Value ($)
1	India	9,937,990	8,071,241,000[a]
2	Turkey	630	378,084,000
3	Russia	506,166	94,513,000[a]
4	Myanmar	499,438	NA[c]
5	Pakistan	446,584	67,212,000[a]
6	Ethiopia	435,193	308,187,000[a]
7	USA	282,91	117,125,000
8	Australia	281,2	102,041,000
9	Canada	251,5	126,882,000
10	Mexico	202,846	128,144,000
11	Iran	200,679	121,804,000
12	Argentina	137,244	4,588,000[a]
13	Morocco	75,413	83,340,000
14	Sudan	73,387	NA[c]
15	Syria	52,419	NA[c]
16	Tanzania	42,155	NA[c]
17	Algeria	40,369	23,284,000[a]
18	Yemen	38,541	70,322,000[a]
19	China	15,606	24,497,000[b]
20	Israel	14	15,710,000
21	Nepal	10,675	10,684,000[a]

[a] includes data of gross production value in 2018
[b] includes data of gross production value in 2017
NA[c] indicates that data is not available for 2017-2019 and values without any subscript showing data of 2019
Source: Food and Agriculture Organization (FAO) (2021)

mainly to assist them in dealing with pests and diseases. Since chickpea cultivation is less profitable than cereals like wheat and barley, as a result, peasants who have access to irrigation prefer to grow cash crops. Significant post-harvest losses owing to poor storage facilities are another issue that developing countries face in chickpea production.

Chickpea production has progressive development over the last few decades. Due to continuing research efforts by international organizations such as ICRISAT and ICARDA, as well as national research and breeding programs, the yield of chickpea has increased significantly. The development of production in new regions, especially North America and Australia, has had a major impact on global production and commodity supply on international markets. World trade has improved dramatically during the last two decades, owing to rising population demands and rising buying power in developing countries. Because of its high nutrient contents and nutritional value, chickpea has an excellent outlook. The output expansion to satisfy the increasing demand for chickpea is expected to continue.

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AUTHOR INDEX

SUBJECT INDEX

AFS– GUIDE FOR AUTHORS

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