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Original Research

Combining Ability Analysis in Sweet Corn (*Zea Mays Saccharrata L.*) Using Line by Tester Design

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ABSTRACT

Aim

The purpose of this study was to investigate the different combination of testcrosses for morphological and yield relating traits and to investigate general combining ability of the inbred lines.

Materials and Methods

This research was conducted at The University of Agriculture Peshawar, Pakistan during 2016. Line x-tester analysis was used to test general combining ability (GCA) effects of 24 S4 lines of sweet corn. Alpha lattice design with two replications and two checks was used during the experiment. Research data were recorded on various flowering, morphological and yield parameters.

Results

Highly significant variations were recorded among the testcrosses for the studied traits except anthesis silking interval (ASI), 100-kernel weight. Minimum days to tasseling (48-days) and silking (53.5-days) was exhibited by pop-syn-swt (9-4)×synthetic sweet. GCA effect was -2.14 for tasseling and -2.00 for silking. Maximum value (3.5-days) for ASI was recorded for Pop-syn-swt 1(8-3)×synthetic sweet, while GCA effect for ASI was -0.71. Lowest plant height (129.8 cm) was recorded for pop-syn-swt 1(3-3)×synthetic sweet, while GCA effect for plant height was observed to be -14.79. Maximum cob length (16.6 cm) was revealed by pop-syn-swt 1(12-2)×synthetic sweet. For cob length GCA effect of 1.01 was recorded. Maximum 100 kernel weight (31.3 g) was estimated for pop-syn-swt 1(2-1)×synthetic sweet. GCA effect of 1.85 was recorded for 100-kernel weight. Highest mean (7143.9 kg ha⁻¹) for grain yield was recorded for pop-syn-swt 1(9-4)×synthetic sweet. GCA effect for grain yield was found to be 1370.93.

Conclusion

Generally a low GCA value, either positive or negative indicates that the mean of a parent does not largely vary from its offsprings. In contrast, high GCA value suggests that parent is either superior or inferior to the general mean and it has high heritability and less environmental effects. Based on the findings in this research, the above mentioned testcrosses can be included in future sweet corn breeding programs where early flowering and yield attributes is desired.

Keywords

Sweet corn; General combining ability; Inbred lines; Line by tester; Yield; Flowering.

INTRODUCTION

Maize (*Zea Mays Saccharrata L.*) is the prime member of family Gramineae. It is the third major source of staple food after

wheat and rice for mankind. It is a short duration crop and can be successfully grown in areas of high mountains of KPK (Khyber Pakhtunkhwa), where snowfalls and chilling temperature limits growing period of cereals.¹ Maize has 5 types i.e flint corn, dent

corn, popcorn, flour corn and sweet corn. Sweet corn (*Zea Mays Saccharata. L*) is a variety of maize having high sugar content. It differs from field corn in terms of its genetic makeup.² It contains high percentage of sugar during milk stage. It is grown in several areas of Khyber Pakhtunkhwa including Mansehra, Mingora and Swabi for local market purpose.³ Potential yield of sweet corn can be maximized through various breeding schemes. In these breeding schemes early testing of S₂ lines is considered an efficient approach for grain yield.⁴ Maize improvement can be boosted due to genetic diversity.¹ To identify better combiners, combining ability analysis is employed.

Combining ability is the capacity of an individual to transmit superior performances to its offspring. The better combiners can be hybridized to exploit heterosis and to select better crosses for future breeding work or direct use. Combining ability analysis is of special importance in cross-pollinated crops like maize as it helps in identifying potential inbred parents that can be used for producing hybrids and synthetics.² Expected value of any particular cross is the sum of general combining ability (GCA) of its two parental lines.⁵ GCA is the ability of a line to produce superior hybrids when crossed with a broad base tester or to a number of different inbred lines. Tester is a line used as female parent in a cross. On the basis of good GCA, when more promising lines are selected it is necessary to find out the particular combination that will produce the higher yield.³ Estimates of GCA provides a guideline of individual genotypes in selection and testing schemes. Hence diallel analysis is one of the genetic-statistical approaches that helps in selection of parents carrying promising genotypic potential of producing superior segregants.⁶ The present study was therefore initiated to 1) evaluate sweet corn testcrosses for yield and morphological traits and 2) estimate general combining ability of inbred lines of sweet corn. Combining ability is the capacity of an individual to transmit superior performances to its offspring. The better combiners can be hybridized to exploit heterosis and to select better crosses for future breeding work or direct use. Combining ability analysis is of special importance in cross-pollinated crops like maize as it helps in identifying potential inbred parents that can be used for producing hybrids and synthetics.² Expected value of any particular cross is the sum of GCA of its two parental lines.⁵ GCA is the ability of a line to produce superior hybrids when crossed with a broad base tester or to a number of different inbred lines. Tester is a line used as female parent in a cross. On the basis of good GCA, when more promising lines are selected it is necessary to find out the particular combination that will produce the higher yield.³ Estimates of GCA provides a guideline of individual genotypes in selection and testing schemes. Hence diallel analysis is one of the genetic-statistical approaches that helps in selection of parents carrying promising genotypic potential of producing superior segregants.⁶ The present study was therefore initiated to 1) evaluate sweet corn testcrosses for yield and morphological traits and 2) estimate general combining ability of inbred lines of sweet corn..

MATERIALS AND METHODS

The research was conducted at The University of Agriculture Pe-

shwar, Pakistan during 2016. Forty-eight testcrosses, derived in spring 2016 by crossing 24 inbred lines with two testers at Cereal Crops Research Institute Pirsabak, Newshehra, were evaluated in alpha lattice design with two replications along with two checks. Each testcross was sown in a 2 row plot, having 4 meter row length. The row spacing was kept 0.75 m while plant to plant spacing was 0.25 meter. Two to three seeds per hill was sown which were later thinned. Data was recorded on plot basis for flowering characters and grain yield related traits, while on randomly selected plants for plant height and ear height. Recorded data was analyzed through WASP (web of Agri AGRISTAT package) software, developed by Ashok Kumar Jangam and Pranjali Ninad Wadekar. Analysis of general combining ability effect was calculated using method developed Kempthorne et al (Table 1).⁷

SOV	Df	MS	F-value
Replications	(r-1)	RMS	RMS/EMS
Crosses	(c-1)	CMS	CMS/EMS
Lines	(l-1)	LMS	LMS/EMS
Tester	(t-1)	TMS	TMS/EMS
Line×tester	(l-1)(t-1)	LTMS	LTMS/EMS
Error	(r-1)(c-1)	EMS	
Total	ltr-1		

SOV=source of variation, Df=degree of freedom, MS=means Square, RMS=replication mean square, CMS=crosses mean square, LMS=lines mean square, TMS=tester mean square, LTMS=line×tester mean square, EMS=error mean square

Estimation of General Combining Ability Effect

$$gi = \frac{(Xi..)}{tr} - \frac{(X...)}{ltr}$$

where t=tester , r=replication and l=lines

RESULTS AND DISCUSSION

Analysis of Variance

Analysis of variance disclosed highly significant variation ($p < 0.01$) among the testcrosses for days to tasseling, plant height and cob length, and significant variation ($p < 0.05$) for grain yield, while non-significant variation for days to silking among the testcrosses (Table 2). Kamara et al⁸ have noticed similar significant results for tasseling, plant height and grain yield. Variation due to lines effect was highly significant for tasseling, silking and plant height, significant for cob length and non-significant for grain yield (Table 2). Variation due to tester effect was non-significant for flowering and yield traits, while highly significant for plant height. Similarly variation due to line and tester interaction was non significant for silking and tasseling, and highly significant for cob length and plant height, while significant for grain yield (Table 2). The pres-

Table 2. Mean Squares for Days to Silking, Tasseling, Cob Length, Plant Height and Grain Yield of 48 Testcrosses Derived from S₄ Lines of Sweet Corn

Source	DTS	DTT	PH	CL	GY
Replication	2.04	7.59	0.68	18.38	399680.63
Crosses	3.23NS	6.04**	257.97**	1.72**	1729930.86*
Lines	5.13*	8.08**	303.97**	1.52*	1614682.90 NS
Tester	2.04NS	1.76NS	17.94**	0.06NS	231624.40 NS
Line × tester	1.43NS	3.47NS	222.41**	2.00**	1910322.58*
Error	2.22	1.99	0.68	0.63	828031.48
CV%	2.66	2.74	0.54	5.65	19.65

*, **=significant at 5 and 1% probability level, respectively. NS=Non-significant
DTS=Days to silking; DTT=Days to tasseling; PH=Plant height; CL=Cob length; GY=Grain yield

Table 3. Means, GCA Effects of Days to Silking and Tasseling of 48 Testcrosses of Sweet Corn

S ₄ Lines	Silking (days)		GCA	Tasseling (days)		GCA
	Tester			Tester		
	CCRI Sweet	Synthetic Sweet		CCRI Sweet	Synthetic Sweet	
I(4-1)	53.5	55	-1.50	49	48.5	-1.66
I(9-3)	55	56	0.50	49	51.5	0.09
I(9-1)	56.5	58.5	-0.50	50.5	54	-1.16
I(8-1)	56	57	1.00	51	51.5	0.09
I(8-4)	55.5	55.5	-0.75	50	50.5	-1.41
I(8-5)	55	54	-0.50	49	48.5	-1.16
I(12-4)	57	55.5	-0.50	50.5	51	-1.41
I(2-4)	56.5	55	-2.00	51	49.5	-2.16
I(6-3)	54.5	59	0.25	49	53.5	0.84
I(3-2)	55.5	56	1.00	49.5	50.5	2.34
I(3-1)	55	57	-0.25	49.5	51.5	0.09
I(12-2)	55.5	58	0.00	49.5	52.5	0.09
I(2-1)	55	55	-0.25	49	50	-0.66
I(7-3)	55.5	56.5	2.00	49.5	55	2.09
I(9-2)	53.5	58	-1.00	48	55	-1.16
I(4-2)	54	57.5	-0.50	49	53	-0.41
I(8-3)	56	54.5	1.75	51.5	49	1.34
I(9-4)	56	53	1.75	51.5	47.5	1.34
I(7-4)	57	55	0.00	53	50	1.84
I(3-5)	56.5	56	2.00	53	51	3.34
I(10-2)	56	56	-2.00	51	51	-2.41
I(3-3)	55	55	-0.25	50.5	50.5	-0.16
I(7-1)	57	56	-0.25	52.5	51.5	0.09
4(3-3)	54.5	55.5	0.00	49	50	0.09
Grand mean	55.47	56.02		50.20	51.10	
Grand mean of checks=55				Grand mean of checks=49.4		

*The S₄ lines pedigree number which were obtained from (cereal crops research institute (CCRI), Pirsabak) Pakistan

ent findings of this research are in direction with earlier research reports of Chen et al,⁴ Srivastava,⁵ Jaykumar et al,⁶ Premlatha et al,⁷ Al Nagger et al,⁸ El-Hosary et al,⁹ and Ali et al.¹⁰

Days to Silking (days)

Means for days to silking ranged from 53 to 59-days having an average of 55.47 with T1 (Central Citrus Research Institute (CCRI) sweet) and 56.02 with T2 (Synthetic sweet) (Table 3). Using synthetic sweet as tester minimum value (53-days) was observed for line 1(9-4) and maximum (59-days) by line 1(6-3). Overall mean of testcrosses was 55.75 and 55-days for checks (Table 3). Mean values ranged from -2.00 to 2.00. highest positive GCA was obtained for line 1(3-5) and lowest for line 1(10-2). Thirteen testcrosses showed negative GCA effect. It is evident from the findings that 37.5% testcrosses took minimum days to silking and 62.5% took more days to silking as compared to checks (Table 3). Negative GCA

effect was recorded for 54.1% of testcrosses (Table 3). Nigussie et al,⁹ reported similar negative GCA effects for days to silking.

Days to Tasseling

Testcross 1(9-4) took minimum (47.5) days to tasseling, with synthetic sweet as tester and maximum (55-days) by line 1(7-3) and 1(9-2), using synthetic sweet as tester. The average mean for all testcrosses was 50.66-days. GCA values ranged between -2.41 to 3.34 (Table 3). Maximum GCA effect was recorded for line 1(3-5), followed by 1(3-2), and minimum for line 1(10-2) followed by 1(3-4). About 35.5% testcrosses took minimum time to tasseling and 64.5% took more time as compared to check means. 48.5% testcrosses recorded negative GCA effect and rest with positive GCA values (Table 3). Our result for days to tasseling got support from Shah et al.¹⁰

Table 4. Means, GCA Effects of Plant Height and Cob Length of 48 Testcrosses of Sweet Corn

S ₄ Lines	Plant Height (cm)		GCA	Cob Length (cm)		GCA
	Tester			Tester		
	CCRI Sweet	Synthetic Sweet		CCRI Sweet	Synthetic Sweet	
1(4-1)	168.5	135	3.36	13.8	15.8	-0.33
1(9-3)	147.6	167.7	11.51	15.1	14.1	0.92
1(9-1)	159.4	153	17.03	15.9	14.1	0.48
1(8-1)	173	155.5	12.76	15.5	15.4	0.13
1(8-4)	173.55	144.6	-1.89	15.9	13.9	-0.14
1(8-5)	169.9	152.1	-8.44	14.6	15.7	0.06
1(12-4)	178	144	0.56	13.6	16.6	-1.37
1(2-4)	156.6	136.6	-2.59	16.3	14.9	1.01
1(6-3)	159.7	157.7	5.61	14.6	16.1	-0.59
1(3-2)	145.9	155.6	1.91	14.7	15.2	-0.32
1(3-1)	148.1	145.9	-4.49	13.9	14.6	-0.49
1(12-2)	144.4	139.3	2.61	15.8	14.8	-1.02
1(2-1)	156	143.5	-3.34	13.6	16.2	0.18
1(7-3)	154.5	148.5	-0.44	13.3	14.4	-0.09
1(9-2)	146.6	160.3	-6.34	15.7	13.7	0.01
1(4-2)	157.6	145.5	-14.39	15.9	14.8	0.98
1(8-3)	144.6	167.2	1.96	14.8	14.5	0.88
1(9-4)	176	176.1	-12.06	13.6	14.8	-0.12
1(7-4)	162	147.9	-8.69	15.3	14.9	0.51
1(3-5)	151.2	165.8	-1.79	13.6	15.1	-0.57
1(10-2)	149.6	150	16.96	15.1	12.9	-0.12
1(3-3)	150.8	129.8	2.16	13.6	15.5	0.18
1(7-1)	163.6	164.3	-14.79	13.4	15.7	-0.59
4(3-3)	151	151	2.96	14.2	14.1	0.38
Grand mean	157.85	151.53		14.67	14.95	
Mean of checks=148.3				Mean of checks=13.10		

*The S₄ lines pedigree number which were obtained from (cereal crops research institute (CCRI), Pirsabak) PAKISTAN

Plant Height

Mean values regarding plant height ranged between 129.8 and 178 cm. Maximum plant height was recorded by line 1(12-4), when CCRI sweet was used as tester followed by 1(9-4) when synthetic sweet was used as tester. Minimum plant height was observed for line 1(3-3), with synthetic sweet as tester (Table 4). GCA effect ranged from -14.69 to 17.03. Maximum positive GCA effect was observed for testcross 1(9-1), succeeded by testcross 1(10-2). Negative and maximum GCA effect was in case of testcross 1(7-1), followed by 1(4-2) (Table 4). Proportional contribution of lines were relatively higher (Table 5). Plant height has direct effect on yield. Higher plants are more susceptible to lodging and decreasing yield. Hence low plant height is ultimate goal of a breeder. In this experiment 27.98% plants had lowest plant height as compared to mean of checks (148 cm). Half of the population recorded negative GCA effects for plant height (Table 4). Early researcher Gul et al¹¹ and Carena¹² also estimated significant results for agronomic trait like plant height.

Table 5. Proportional Contribution Lines, Tester and Line×Tester Interactions for Various Traits of Sweet Corn to the Total Variance

% Contribution	Silking	Tasseling	Plant Height	Cob Length	Grain Yield
Lines	77.12	71.23	57.66	43.22	45.68
Tester	1.33	0.62	0.15	0.08	0.28
Linex tester	21.54	28.15	42.19	56.70	54.04

Cob Length

Large seed set can be obtained only if cob length is high. Mean value regarding cob length were between 12.9 to 16.6 cm. Line 1(12-4)×synthetic sweet was found to be with high cob length mean, while lowest mean was recorded for testcross 1(10-2)×synthetic sweet. Mean of checks was lower than mean of testers (Table 4). General combining ability effect values lied in range of -1.37 and 1.01. Desirable and high GCA effect value was observed for testcross 1(3-4), while testcross 1(12-4) recorded negative GCA effect with minimum value (Table 4). In the present study about 97% population had higher cob length mean than compared to checks mean. It was evident from the results that 50% of testcrosses had positive GCA effects (Table 4). Contribution of lines was lower than line and tester interaction (Table 5).

Grain Yield

Mean values for GCA ranged between 2022.04 and 7143.18 kg ha⁻¹ (Table 6). Highest mean 7143.18 was recorded for testcross 1(9-4), using synthetic sweet as tester, and 6647.72 for testcross 1(8-1), using CCRI sweet as tester, while lowest mean 2022.04 was shown by testcross 1(7-4), using synthetic sweet as tester, and 3715.90 by testcross 1(9-3), using CCRI sweet as tester. Mean of checks was found lower (4086.39 kg ha⁻¹) (Table 6). GCA effect was in range of -1133.35 to 1370.93. Maximum GCA effect was shown by testcross 1(10-2) and minimum GCA effect was recorded for testcross 1(7-4). Twelve testcrosses showed positive GCA

effects (Table 6). About 33.3% testcrosses had highest mean for grain yield and 66.6% had lowest mean when compared to mean of check. Among testcrosses, 45.8% had positive GCA effects and 54.8% had GCA effects in negative direction. Similar significant results were also disclosed by Rahman et al¹³ for grain yield in maize breeding program. Similar results for grain yield due to GCA and SCA were reported by Menkir et al.¹¹

Table 6. Means, GCA Effects of Grain Yield of 48 Testcrosses of Sweet Corn

S ₄ lines	Grain yield (kg ha ⁻¹)		GCA
	Tester		
	CCRI Sweet	Synthetic Sweet	
1(4-1)	4911.21	4800.45	-457.05
1(9-3)	3715.91	4733.94	1281.93
1(9-1)	5657.27	3792.42	-754.02
1(8-1)	6447.73	5916.97	194.80
1(8-4)	3942.27	3980.83	-4.25
1(8-5)	4090.91	4377.20	473.78
1(12-4)	5303.03	5385.91	-54.55
1(2-4)	4627.73	3837.88	268.73
1(6-3)	4751.52	4864.85	-324.15
1(3-2)	4781.21	5203.64	162.83
1(3-1)	5178.79	5296.67	183.78
1(12-2)	5310	2180	818.05
1(2-1)	5189.70	3815.91	-3.37
1(7-3)	4242.42	3458.79	84.08
1(9-2)	4615.15	5286.67	-591.57
1(4-2)	5463.48	4239.92	-158.67
1(8-3)	4614.92	5139.85	263.63
1(9-4)	4277.95	7143.18	-1032.27
1(7-4)	5542.42	2022.05	-1133.25
1(3-5)	4324.39	5759.39	-7.32
1(10-2)	5032.73	4267.58	1370.93
1(3-3)	4876.06	4951.97	-879.87
1(7-1)	5302.27	4620.98	-160.85
4(3-3)	5875	5837.50	458.65
Grand mean	4919.75	4621.43	

Mean of checks=4086.39

*The S₄ lines pedigree number which were obtained from CCRI (cereal crops research institute, Pirsabak) Pakistan

CONCLUSION

The findings of this research suggested extent of variability among the testcrosses for different traits studied, which could be further evaluated in certain future breeding schemes involving sweet corn. Testcross 1 (9-4), 1(12-4) and 1(3-3) is recommended for grain yield, cob length and plant height respectively. However, in terms of GCA effects testcross 1 (10-2) can be fruitful in future

breeding programs as it had showed negative general combining ability estimates for days to silking and days to tasseling which is desirable for flowering traits, and for plant height and grain yield the said testcross exhibit positive maximum GCA effects.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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Review

Dietary Recommendation in Diabetes Care: Carbohydrate Counting and Caloric Content of Nigerian Foods

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ABSTRACT

The prevalence of diabetes mellitus is rising globally and even more in low and middle-income countries such as Nigeria. Optimal management of the disease is important to improve survival and prevent or delay its complications. Lifestyle management is a standard universal approach in optimizing the care given to diabetic patients. Dietary management is the central link in lifestyle modifications of individuals living with diabetes. Medical nutrition therapy (MNT) is a systematic therapeutic approach of assessing the nutritional needs of an individual, determining nutritional goals, counselling the clients on how to achieve the goals, prescribing and monitoring meal plans to achieve the goals. It is evidence-based, effective and highly recommended. All carers of the diabetes patient, including the health workers and the family members of the patients, need to have basic understanding of medical nutrition therapy but the efforts should be coordinated by licensed dietitians. There are evidences that adherence to prescribed calories is effective in the control of cardiovascular risk factors such as blood glucose, weight, lipid profile and blood pressure. However, prescription of calories should be based on thoughtful consideration of the nutritional needs, weight goal, personal preferences and tastes and cultural practices of individuals living with diabetes mellitus. Food pyramids give a graphical illustration on the recommended classes and servings of food. Six to eleven servings per day of carbohydrates, 3-5 servings per day of vegetables, 2-4 servings per day of fruit, 2-3 servings per day of dairy products and 2-3 servings per day of fish are the recommended proportions of the different classes of foods for an adult on an average of 2000 calories. Carbohydrate counting, taken with appropriate insulin dosing and physical activity, has been demonstrated to be effective in optimizing the glycaemic control of patients on multiple daily insulin injections. There are challenges in doing this in Nigeria due to lack of food labels. The caloric contents of common Nigerian foods are highlighted so as to help in achieving dietary goals.

Keywords

Diabetes care; Dietary approach; Carbohydrate counting; Caloric content of Nigerian foods.

BACKGROUND

Lifestyle management is the pedestal of optimal care in individuals with diabetes and dietary approach is the central theme of lifestyle modification. Healthy eating is the cornerstone of glycaemic control in diabetes mellitus.¹ Glycaemic control refers to the methodical approach to achieving the glucose targets (Fasting blood glucose, postprandial glucose and glycated haemoglobin) of patients with diabetes mellitus depending on the adopted guide-

lines. However, recommendation about dietary management may be difficult in Nigeria, where the number of registered dietitians under employment is limited. Also, there is lack of knowledge of the caloric contents of Nigerian foods. The notion of 'diabetic diet' which involves a lot of dietary restriction is being replaced with 'healthy diet' which is having a dietary plan adequate in nutrients and moderate caloric and fat contents. So, the 'healthy diet' is the recommended diet for everyone. This makes the individuals living with diabetes mellitus feel socially acceptable while also en-

couraging them to comply with their recommendation.

Patients with diabetes are expected to see the dietitians, at least, at diagnosis. However, in low resource settings, availability of professional dietitians under employment is limited so, it is important for all carers of patients with diabetes, including their family members, to understand the dietary approach to their care. Nigeria is a multicultural society with various kinds of foods and food preparations.² Dietary management in patients with diabetes and prediabetes is aimed not only at optimizing glycaemic control but also at control of other cardiovascular risk parameters such as weight, lipids and blood pressure.³ Consumption of excess calories, even without causing hyperglycaemia, is an independent cardiovascular risk.³ Dietary prescription involves a collaboration among the patient and his family, the dietitian and the physician based on health targets (such as weight and blood glucose readings), cultural values, lifestyle, dietary preference and taste.⁴

Healthy sources of carbohydrates available in Nigeria include whole grains (such as rice, maize and millet) and legumes (such as beans and groundnut). Low fat dairy foods such as milk or cheese are also recommended. As healthy as they are, studies have demonstrated that the knowledge of the health benefits as well as the consumption of fruits and vegetables is very low among Nigerians despite the extensive availability of varieties of fruits and vegetables.⁵ Consumption of sugary beverages with extra calories is often discouraged but a study documented a high-level of consumption of sweetened beverages among Nigerians.⁶ Saturated fats are discouraged but food sources such as organ meat (kidney, intestine and liver) rich in saturated fats are commonly consumed in Nigeria.⁷ High salt intake (more than 5 grams of salt per day) which is unhealthy is prevalent in Nigeria and many other sub-Saharan countries, as reported by a meta-analysis.⁸ The plate method of meal planning recommended by the American Diabetes Association (ADA) involves filling half of the serving plate with vegetables, a quarter of the plate with carbohydrates and the remaining quarter with proteins.⁹ A serving of dairy and a cup of water can accompany the plate. This is not practiced among Nigerians with or without diabetes mellitus.⁷

Carbohydrate counting has beneficial effects on glycaemic control.¹⁰ It helps in determining the appropriate insulin doses to prevent fluctuating glycaemic patterns. It adds flexibility to the management and engenders compliance. In Nigeria, more efforts are tailored towards controlling glucose excursions by appropriately adjusting insulin doses rather than teaching and practicing carbohydrate counting.¹ This is partly due to the fact that there are insufficient data on the carbohydrate and caloric contents of Nigerian foods and the methods of food preparation for consumption vary remarkably from one region to the other.¹¹

It is a common dietary advice to tell patients to lower their caloric intake. In the developed world, appropriate food packaging and compulsory food labelling make it relatively easy for patients to achieve their calorie targets.¹² In Nigeria, foods are often prepared in households or at restaurants without any form of food labelling.¹³ Even among the elites who sometimes consume pack-

aged meals, a study reported that they rarely check the labels and the few who check find them confusing.¹³ Variation in species and variants of the crops, food processing and food preparation also tend to make estimation of food caloric content inaccurate, hence why it is rarely focused on.¹²

MEDICAL NUTRITION THERAPY

Medical nutrition therapy (MNT), also known as therapeutic nutrition is an evidence-based and systematic process of assessing the nutritional status and requirements of an individual, setting nutritional goals, counselling on how to achieve the goals, prescribing and monitoring meal plans to achieve the goals.¹⁴ The terminology 'medical nutrition therapy' was first used by the ADA in 1994 but the concept of recommending diets for patients with diabetes dates back to antiquity.¹⁴ Several researchers have documented the clinical benefits of MNT in the management of diabetes.¹⁴ Evidences from observational studies, cohort studies, randomized clinical trial and meta-analyses are in support of this assertion. Apart from the clinical benefits, economic studies have also found MNT to be cost-effective.¹⁵

While it is essential that every member of the diabetes care team knows about nutrition and is able to offer valuable nutritional advice, it is recommended that the dietitian should spearhead medical nutrition therapy.¹⁶ In fact, a meta-analysis documented that diabetic patients who received MNT from a registered dietitian had more reduction in glycated haemoglobin (HbA1c) compared with those who received dietary advice from nurses or physicians.¹⁷ In Nigeria, there are insufficient numbers of dietitians to provide MNT for all the diabetic patients as most of the registered ones cluster in urban centres, mostly at the secondary and tertiary levels of care.

Medical nutrition therapy emphasizes individualized care because fixed ratios of carbohydrates, proteins and fats cannot be applied to everyone with diabetes due to differences in their nutritional requirements.¹⁸ Mediterranean diet has been found to be the most effective diet type in terms of lowering of HbA1c.¹⁹ Mediterranean diet refers to the meal plans commonly consumed among countries bordering the Mediterranean Sea. There is no universal definition of Mediterranean diet, but it is essentially based on whole grains, fruits and vegetables, dairy products, use of healthy fats such as olive oil and minimization of red meat consumption.²⁰ The pattern of eating among patients with diabetes in Nigeria is different from the Mediterranean diet as it is based on calorie-dense high carbohydrate diet.²¹ Also, in a developing nation like Nigeria, where there is paucity of dietitians under employment, fixed ratios of food classes is still being practiced. About 45-65% of the total daily calorie is allotted to carbohydrates, fats constitute about 25-35% and proteins constitute about 15-20%.¹ It is also a common misconception among the diabetic population that consuming carbohydrates is tantamount to hyperglycaemia so, they tend to avoid carbohydrates or minimize its consumption.¹

Prior to the landmark discovery of insulin and its com-

mercialization, a very low caloric diet, known as Allen diet, was used in treating diabetes.¹ The advent of insulin therapy means carbohydrate content of the meal could be increased to as much as 50%. However, in Nigeria, the composition of dishes consumed by diabetic individuals is still dependent on the socioeconomic status of the patient, cultural food beliefs, seasonality and availability of food.²² In addition, most of the meals are composite diets so, it is difficult to synthesize data on the caloric content of the meals.

PRESCRIPTION OF DIETS FOR PATIENTS WITH DIABETES

It is recommended that prescription of diet for people living with diabetes should not be fixed but should depend on nutritional assessment, requirement, goals, individual preferences and the cultural milieu.²³ The goals of dietary prescription are to improve cardiometabolic parameters (blood glucose, weight, abdominal circumference and blood pressure) and prevent, delay the onset or prevent the progression of diabetes complications.²⁴ These are not to be achieved at the expense of pleasurable enjoyment of meals and disregard of cultural values and beliefs. Attention should be placed on the unique needs of special people such as the growing child or adolescent with type 1 diabetes, pregnant or lactating women and patients on meal-related medications such as insulins or insulin secretagogues to avert both hyperglycemia and more importantly, hypoglycaemia.²⁴

Studies have shown that with good adherence, prescribed diet can lower HbA1c by 1-2% within 3-6-months.²⁵ In obese or overweight patients, the prescription should be aimed at moderate weight loss (5-10% of present body weight).²⁴ This is achievable with a low carbohydrate and low fat diet. Carbohydrates with low glycemic index should be prioritized. Glycaemic index of food is defined as the extent of rise of blood glucose

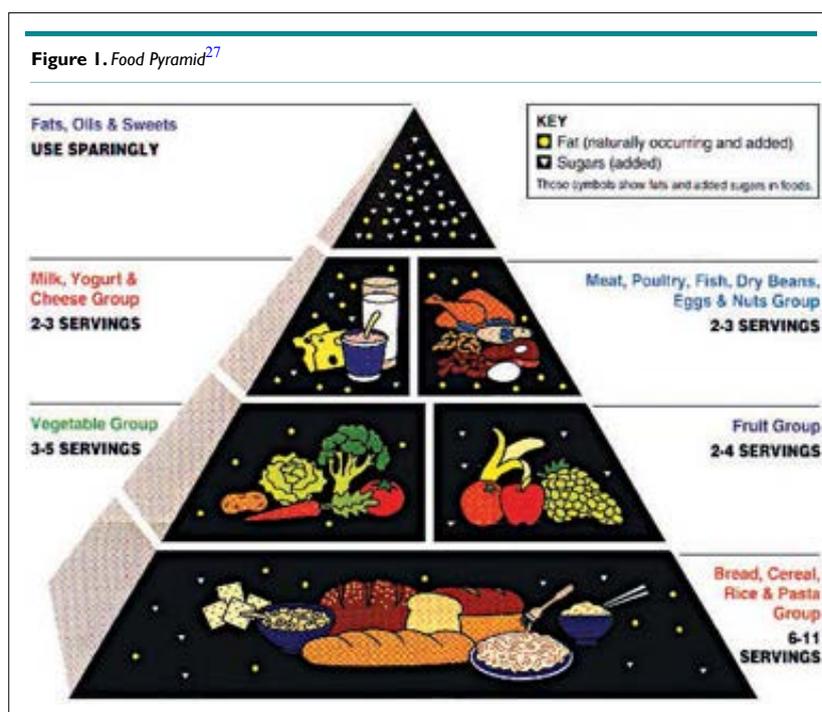
after taking the food compared with a rise in glucose after ingesting a reference food (usually glucose or white bread).²⁴ The glycemic index of a food multiplied by the amount of carbohydrate in the food gives the glycaemic load.²⁴ Whole grains and legumes are good sources of carbohydrates because they have low glycaemic indices.

Considering prescription for fats, saturated fats should be limited to <7%, trans-fat is better avoided altogether while cholesterol should be limited to <200 mg per day.²⁴ Monounsaturated fat is highly recommended. High protein diets are not recommended. Good quality proteins provide the 9 essential amino acids. Examples of quality protein that are available in Nigeria are fish, eggs, milk and poultry. Mineral or vitamin supplementation to the diets of people living with diabetes is not recommended.²⁴ However, special groups such as elderly, pregnant or lactating women and individuals on very low calorie diet may benefit from supplementation.²⁴

FOOD PYRAMID

Adequate diet is the diet that provides needed nutrients in a proportion that meets the physiological needs of an individual. Food pyramid is the scheme used to depict food classes and the appropriate proportion of each class.²⁶ The pyramid is divided into layers and each layer corresponds to the relative amount and class of food. It is triangular and graphically represents food proportions designed in a way to support healthy eating. The base is represented by carbohydrates, and progressing upwards, this is followed by vegetables, followed by proteins and lastly fats and sweets.²⁶ The progression from the base to the tip represents the relative quantity of each class to be consumed with the base representing the largest quantity and the tip representing the smallest quantity.

Generally, it is recommended to have 6-11 servings per



day of carbohydrates (rice, bread, cereals), 3-5 servings per day of vegetables, 2-4 servings per day of fruit, 2-3 servings per day of dairy products and 2-3 servings per day of fish.²⁶ The concept here is that no single food has all the needed nutrients in adequate doses and appropriate variety is the key. This is illustrated in Figure 1 below.²⁷

CARBOHYDRATE COUNTING

This is a technique used by patients with diabetes to estimate the amount of carbohydrate in their meals. The carbohydrate quantity is determined in grams and a serving of carbohydrate is about 15 grams.²⁸ The health care giver and the patient agree on how much carbohydrate to aim at so as to reach the nutritional goal. Appropriate combination of carbohydrate counting, physical activity and insulin dosing is important for optimal glycaemic control. Carbohydrate counting entails keeping track of the carbohydrate in the diets. It helps to stay healthy and prevent or delay the onset of complications of diabetes. The amount of carbohydrates is often inscribed on the food label.

Carbohydrate counting is illustrated as follows. Assuming the daily calorie recommendation for a man is 1800 Kcal per day, it is recommended that carbohydrate should constitute about 50% of this total calorie level, thereby making total calories from carbohydrate, in this instance, 900 Kcal.¹ Four kilocalories (Kcal) is derived from 1g of carbohydrate, therefore 900 Kcal will be derived from 225 g of carbohydrate. This can be divided into 3 meals and 1 to 2 snacks.

In Nigeria, carbohydrate counting is not usually advised during a dietary counseling session. Instead the recommendation used is to restrict one or more forms of carbohydrate.¹ Most foods consumed are prepared at home or bought unpackaged or without a food label. However, it is now known that the amount of carbohydrate eaten is more important than the type because any carbohydrate consumed in sufficient quantity is capable of raising the blood glucose dramatically.¹

Carbohydrate counting adds flexibility to the meal plans,

diet choices and timing of meals. It enables the patients with diabetes to take charge of their health and also to estimate amount of insulin required per certain amount of carbohydrates.²⁸ Carbohydrate counting also assists the patient to observe how the blood glucose responds to different types of carbohydrate and how to respond to it appropriately by adjusting the insulin dose. It is however cumbersome for some people. Moreover, in low resource settings, such as Nigeria, where food labels are the exceptions and there are wide variations in food preparations, it is very difficult to practice food counting without the aid of a registered dietitian.¹³

CALORIE CONTENTS OF COMMON NIGERIAN FOODS AND DRINKS

Foods are often culturally determined and Nigeria is a multicultural nation but there are certain foods that are commonly consumed in most households in Nigeria. There is a need to pay attention to calories so as to meet the dietary goals. Normally, a physically active man requires about 2000 calories per day and an average physically active woman requires 1800 calories per day.²⁴ The main challenge of estimating calories in Nigeria foods is the varied methods of food preparations. Another challenge is the standard of measurement, which tends to vary also. Nutrition education is scarcely available to the populace, especially the rural area dwellers.²⁹ The tables below show the estimated calories in various Nigerian foods and drink (Tables 1, 2, 3 and 4)³⁰⁻³³

Table 1. Estimated Calories of Foods Consumed as Morsels ('swallows') in Nigeria

Swallow	1 Milk Tin of Flower or Flakes
Amala	1 milk tin of yam flour=350 calories
Foofoo (fufu/akpu)	1 milk tin of cassava flour=330 calories
Garri (Eba)	1 milk tin of cassava flakes=360 calories
Pounded yam	Slices of yam equivalent to 1 milk tin of yam flour=400 calories
Semovita	1 milk tin of wheat flour=600 calories
Tuwo (white corn meal)	1 milk tin of corn flour=450 calories

Table 2. Estimated Calories in Beverages ('Drinks') in Nigeria

Alcoholic Beverage	Estimated Calorie Content per 100 ml of Beverage	Caloric Contents in the Bottles Commonly Sold
Gulder	55 calories	1 bottle (600ml)=330 calories
Guinness	45 calories	1 bottle (440 ml)=200 calories
Heineken	35 calories	1 bottle (440 ml)=155 calories
Red wine (13% alcohol)	70 calories	1 bottle (750 ml)=525 calories
Champagne	75 calories	1 bottle (750 ml)=560 calories
Non-Alcoholic Beverage		
Coca-cola coke	42 calories	1 bottle (600ml)=250 calories
Fanta	36 calories	1 bottle (600ml)=220 calories
Pepsi	40 calories	1 bottle (600ml)=240 calories
7 up	42 calories	1 bottle (600ml)=250 calories
Hollandia yoghurt	66 calories	1 bottle (1000ml)=660 calories
Maltina	56 calories	1 bottle (330 ml)=190 calories
Chi exotic	52 calories	1 bottle (1000ml)=520 calories

Table 3. Estimated Calories in Other Staple Foods in Nigeria

Food	Estimated Calorie Content per 100 g of Food	Caloric Contents in Specific Measures
Rice	150 calories	1 tablespoon=15 calories
Beans	140 calories	1 tablespoon=15 calories
Yam	120 calories	1 tuber=highly variable
Bread	300 calories	1 slice=120 calories
Egg	150 calories	1 egg=70 calories
Granulated sugar	-	1 tablespoon=30 calories
Sugar cube	-	1 cube=10 calories
Honey	-	1 tablespoon=60 calories
Powdered milk	-	1 tablespoon=40 calories
Snail	100 calories	-
Palm oil/coconut oil	-	1 tablespoon=40 calories
Akara (beans cake)	-	1 roll=70 calories
Pap (akamu)	-	1 tablespoon=90 calories
Roasted corn		1 medium size=100 calories
Goat meat	100 calories	-
Margarine/butter	-	1 tablespoon=100 calories
Egusi soup		1 serving=500 calories
Ewedu soup		1 serving=100 calories
Okra soup		1 serving=150 calories
Bitter leaf soup		1 serving=150 calories
Oha soup		1 serving=180 calories
Stew		1 serving=200 calories

Table 4. Estimated Calories in Beverages ('Drinks') in Nigeria

Fruits	Estimated Calorie Content per 100 g of Fruit	Approximate Calories per Average-sized Fruit
Apple	55 calories	95 calories
Banana	85 calories	105 calories
Orange	50 calories	65 calories
Pineapple	50 calories	450 calories
Watermelon	30 calories	450 calories
Mango	60 calories	200calories
Garden egg	25 calories	140calories
Pawpaw	80 calories	180 calories

CONCLUSION

Diabetes mellitus is a common chronic disease globally and specifically in Nigeria. A central approach in its management is lifestyle modification. Dietary management is an integral part of the lifestyle modifications. Medical nutrition therapy involves assessing nutritional needs, setting nutritional goals and embarking upon dietary actions to achieve these goals. It also includes monitoring of the patients to ensure the dietary goals are achieved but not at the detriment of the health of the individuals. Dietitians are the primary professionals recommended to lead this effort but the registered dietitians in Nigeria are scanty and mostly distributed in the urban areas.

Food pyramids is a graphical representation of the balanced nutritious diets. Prescription of calories involves taking cognizance of factors such as food availability, weight targets, individual preferences and cultural beliefs and practices. The estimated caloric contents of the common Nigerian foods are highlighted in the tables. However, the exact caloric content is affected by species of crops, food processing and preparations and cultural practices.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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Original Research

Influence of Nutritional Awareness on Grocery Shopping by Kuwaiti Parents in Relation to Children Nutrition

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ABSTRACT

Background

Caregivers, specifically parents, are ultimately responsible for the nutrition of children living in the household, in spite of the children's preferences for food items. There have been no studies on the relationship between the nutritional knowledge level of Kuwaiti parents who grocery shop and their children's nutrition. Therefore, this study was carried out to explore grocery shopping patterns of Kuwaiti parents in relation to their children's eating habits.

Methods

A questionnaire was administered by 4 of the authors through face-to-face interviews with 100 Kuwaiti parents who grocery shop for their families. The questionnaire was designed to cover three main categories: demographics, parents' nutritional knowledge, and children's nutrition. Subjects were interviewed at random at 6 supermarket locations. Data were analyzed utilizing a SPSS statistical package and the Chi-Square test was used to examine the association between variables at the $p < 0.05$ level of significance.

Results

Demographic data of respondents showed that 92% were married, 66% were females, 61% were university graduates, and 84% allowed children to choose food items while shopping. Children's age ranged from 2 to 18-years. Results indicated that the media was the main source of nutrition knowledge of participants. About 50% were familiar with food labels, 74% were shopping for nutrition claims and most parents (60%) were shopping for low-fat products. Analysis of data revealed several associations among demographics, nutrition knowledge of parents and nutrition of children.

Conclusion

This study is the first of its type to be carried out in Kuwait. It revealed several important aspects of parents' background and awareness of nutrition as influencing factors on their grocery shopping. It is hoped that this line of research will be expanded, for the benefit of children's health and avoidance of future nutrition-related diseases.

Keywords

Children; Health; Kuwait; Nutrition interest; Nutrition knowledge; Parents.

INTRODUCTION

Nutrition-related diseases are still increasing among children in Kuwait.^{1,3} Kuwaiti children are gradually getting engaged in further negative dietary habits.^{2,4} Caregivers, specifically parents, have a major influence in providing either healthy or unhealthy

foods to their children – thus, playing a role in shaping their children's health.^{5,6} The main factor of children's food choices is strongly controlled by parent's food choices.^{7,9} A healthy diet helps children to grow normally and learn, as well as help in preventing obesity and weight-related diseases such as cardiovascular diseases, type II diabetes, cancer, and anemia.^{10,11}

As more parents work away from home, their children's eating patterns continue to deviate from being healthy by time and so does their health.¹² Some working parents claim they do not have the time to prepare meals for their children on a daily basis; thus, they opt for what is ready and easy to feed them.¹³ Previous studies showed that children's preference and intake patterns are largely a reflection of the foods that they have become familiar with.¹³ Therefore, caregivers' consumption of food items is positively related to their availability at home. Parents may understand that fruits and vegetables provide vitamins and minerals that are essential for their children's growth.¹⁴ Also, they may have other plant-based food items that contain nutrients that are thought to be important in reducing the risk of some diseases.¹¹ However, such healthy dietary patterns could be overlooked by parents in the face of convenience.

The older generations of parents suffer from various health diseases, which may sometimes be traced back to food eating patterns.¹⁴ Generally, the older generations have a traditional eating pattern and are somewhat stubborn about changing their lifestyle; therefore, not much can be done to dispel their traditional lifestyle and eating habits.^{5,15} As demands for medications in Kuwait increase, therein lays the hope to decrease the risk of those same diseases for younger generations.³ As time changes and nutritional information are discussed openly in society, lifestyle changes such as understanding the importance of fruits and vegetables in one's diet are also occurring. In present days, studying the grocery shopping habits of Kuwaiti parents can offer this study a window on their children's eating patterns since their eating patterns are largely shaped by their parent's food choices.¹⁴

The ready-to-eat meals, fast food, junk food items (e.g., candy bars, cookies, and potato chips), and sugary soft and artificially flavored drinks tend to make up the majority of the Kuwaiti child's diet.¹⁵ Unfortunately, while these food choices and eating patterns continue to grow, diseases such as obesity and diabetes increase amongst children in Kuwait.¹⁶ Parents powerfully shape their children's early experiences with food and eating and provide food choices for them. Children are very much ready to learn to eat the foods of their adult's diet, and their ability to learn to accept a wide range of foods is remarkable.^{2,10,11} The nutritional knowledge level of parents highly influences their children's consumption of fruits, vegetables, and other food choices - in addition to being the link to decreasing the risk of children's health disorders.^{3,6,16,17}

Studies on patterns of grocery shopping by Kuwaiti parents and consequences of such on their children's nutrition are lacking. Thus, this study was of interest to assess aspects of Kuwaiti parents' food shopping choices as influenced by demographic factors and by their level of nutritional awareness. This study will open the door for further studies of the same emphasis, which will enhance nutritional education and the realization that food plays a crucial role in a child's life and health other than just satiation.

METHODS

Participants

A cross-sectional study was carried out among Kuwaiti parents

aged between 18 to 50 years and above who grocery shop for their families. The subjects of this study were randomly selected 100 Kuwaiti parents who were grocery shopping at 6 supermarkets at different locations supermarkets were chosen in mostly Kuwaiti citizens residential areas. This was intended to enhance the chances of having Kuwaitis as subjects for this study. Two different sectors for grocery shopping were represented: the public sector which are known as co-operatives and privately-owned supermarkets.

Administered Questionnaire

Data collection was based on a questionnaire of 28 items that was designed to cover three main categories: demographics, parents' nutritional knowledge, and children's nutrition. Four senior nutrition students visited the 6 supermarkets. Students grouped into two pairs, collected information from 100 parents who were grocery shopping. Random costumers of the survey's age groups were selected and asked if they were parents then interviewed. To conduct the interview, members of the study branched off in groups of two and approached individuals or couples while they were doing their shopping. After asking for their permission to participate in the survey, the inquiry was initiated and per their consent. Naturally, there were some people who hesitated; however, most were agreeable to respond to the questions being interviewed. One interviewer asked the questions, and the other recorded the responses. Participants were interviewed during different hours of the day.

Data Management

After checking for completeness of responses, the interviewing team proceeded to the processing stage. Data of all questionnaire items were entered electronically into a Microsoft Excel document to create charts presenting the collected responses and to find out relationships between each set of data. Data were then analyzed by using Statistical Package for the Social Sciences (SPSS), version 16 (SPSS Inc, Chicago, IL, USA) to aid in tabulating and simply presenting the findings. The Chi-Square test was used to examine the association between variables at the $p < 0.05$ level of significance.

RESULTS

Demographic Characteristics

As shown in Table 1, this study included 100 Kuwaiti parents. Most of the respondents were women (66%). The age of parents ranged from 18-45 years and above. Most of the parents (92%) were married, and (63%) of participants were college graduates. Results showed that 56 % of the participants were working parents while 44 % were not. Most of the parents (71%) were with high monthly household income of (1000-2000 KD/month). Half of the participants had 1-3 children. The children's age ranged from 2-10 and 11-18, which were almost equal in percentage. The majority of participants (61%) shopped at co-operatives and 30% preferred shopping at privately-owned supermarkets. Most of the parents (84%) allowed their children to choose their food while grocery shopping.

Table 1. Demographic Information of Kuwaiti Parents Who Shop for Groceries (n=100)

Item	Description	%
Gender	Male	34
	Female	66
Age of parent	18-30	19
	31-45	37
	>45	44
Marital status	Married	92
	Divorced	7
	Widowed	1
Education level	Graduate	63
	Undergraduate	19
	High School	18
Work status	Working	56
	Not working	44
Family income (KD/mo)	200-900	23
	1000-2000	71
	>2000	6
No. of children	1-3	50
	4-6	42
	>6	8
Age of children	2-10	53
	11-18	47
Where do you usually grocery shop?	Private supermarket	30
	Cooperative	61
	Both	9
Do you allow your children to choose their own food while grocery shopping?	Yes	84
	No	16

Information on child health disorders and awareness of parents about special nutrition regimens are shown in Figure 1. The results showed that 20% of the subjects had children with health disorders. More than half of the participants thought that children with health disorders require special diets; however, only 60% of the parents with health disordered children were following a special diet for their children.

Nutrition Knowledge

Information items on nutrition knowledge of respondent parents are presented in Table 2. Media was the major source of parents' nutrition information (54%), followed by family doctors (20%), books and magazines (20%), and friends (6%). About half of participants (51%) were familiar with the nutrition fact label, with calories being the most important factor in the label (26%). The majority of parents were shopping for nutrition claims (74%). Low fat products (60%) were the major concern for parents to seek, followed by smaller percentages of products that were natural, organic, low sugar, or cholesterol-free - respectively. More than half of the participants (54%) had enough knowledge of the food ingredient label. Most of parents (58%) were purchasing ready to eat meals. The mostly consumed food group by children

was meat (60%). About 43% of the parents felt that their children were not consuming enough fruits and vegetables. The majority of parents (92%) allowed their children to consume junk foods, juices, and sugary soda drinks.

Table 2. Parent's Nutrition Information and Health Data

Item	Description	%
Source of nutrition information	Media	54
	Family doctor	20
	Books and magazines	20
	Friends	6
Are you familiar with food label?	Yes	51
	No	49
Most important information of the nutrition fact label	Calories	26
	Fat	17
	Salt	3
	Sugar	16
	All	5
Shopping for nutrient claims	None	33
	Yes	74
	No	26
Knowledge of food ingredient label	Yes	54
	No	46
If yes, what food label ingredient?	Sugar	4
	Additives	48
	Allergy components	6
Purchasing ready-to-eat meals	None	42
	Yes	58
	No	42
Most eaten food groups	Dairy	11
	Meats	60
	Fruits	3
	Vegetables	6
	Grains	16
Do you allow your children to choose their own food while grocery shopping?	All	4
	Fruits	20
	Vegetables	32
	Grains	5
Do you allow your children to consume these items?	All	43
	Junk food	39
	Juices	34
	Soda drinks	20
	None	8

Children Nutrition

As shown in Table 3, most of the food cooked at home was prepared by mothers (47%) and cooks (42%). More than half of the parents considered the home-made meals to be healthy. Most parents (51%) considered their child's diet to be healthy. As about packing food to school, most of them (59%) did not pack meals for their children for school. The great majority of parents (97%) indicated that they offer guidance for their children to eat healthy.

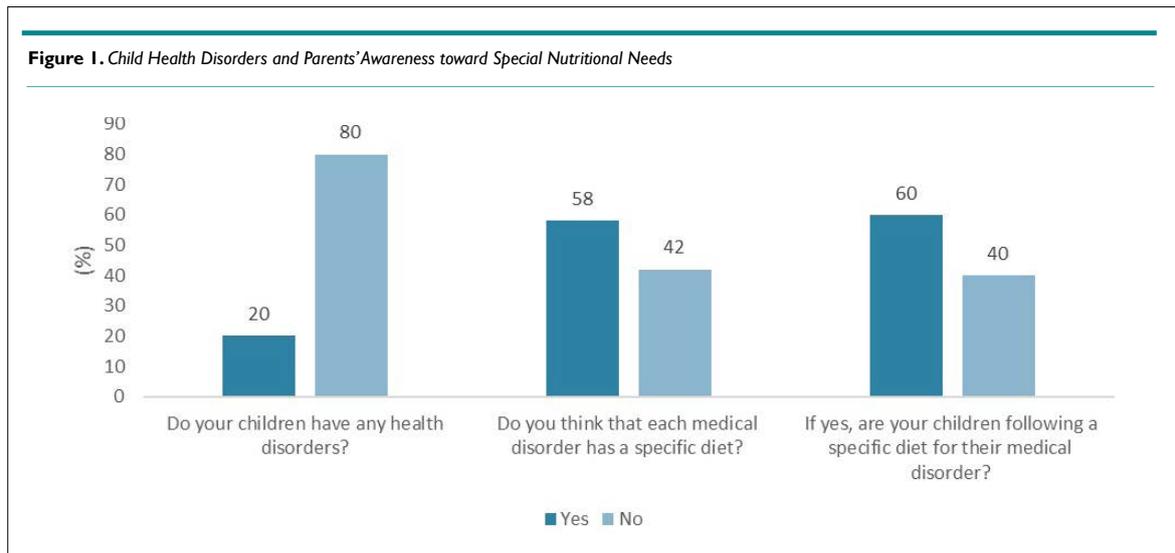


Table 3. Information on Food Preparation and Nutrition of Children

Item	Description	%
Who cooks?	Mother	47
	Cook	45
	Caregiver	6
	Father	2
Healthy meal	Yes	51
	No	34
	Sometimes	15
Pack for school	Yes	35
	No	59
	Sometimes	6
Healthy diet	Yes	51
	No	43
	To a limit	6
Guiding role	Yes	97
	Sometimes	3

Association between Awareness of Nutrition Fact Label and Demographics

Data on the relation between demographic characteristics and awareness of nutrition fact labels are shown in Table 4. Gender of respondent parent had no significant effect on the awareness of the nutrition fact label. Meanwhile, there was a significant ($p=0.001$) effect between age of parents and awareness of nutrition fact label, showing that parents aged >50 are less familiar with the label than younger parents. Marital status had no significant effect on the level of awareness of nutrition fact label. There was a significant effect of the education level of parents on the knowledge of nutrition fact label ($p=0.003$), meaning that parents who were college graduate parents had more familiarity with such label - compared to parents with less educational levels. With regard to the employment status of parents, working parents were

significantly ($p=0.047$) more familiar with the nutrition fact label than those who were not working. Family income, shopping location, and presence of children health disorders had no significant effect on the awareness of the nutrition fact label. There was a significant difference between the awareness of food label of the parents and allowing children to choose their food. More than 90% of parents who were unfamiliar with the food label allowed their children to choose their food, compared to 76% of parents who were more familiar with the food label. There was a significant effect of the level of awareness of nutrition fact label and allowing children to consume unhealthy food.

Association between Consumption of Fruits and Vegetables with Demographics

Data on the relationships between demographic characteristics and consumption of fruits and vegetables by children are presented in Table 5. There was a significant effect of the parents age and consumption of enough fruits and vegetables. The older the parents, the more lack of consuming fruits and vegetables. There were no significant effects of the education level, working status, family income or number of children on the consumption of enough fruits and vegetables. However, there was a negative significant association between children's health disorders and consumption of fruits and vegetables ($p=0.001$), showing that the majority of children who had disorders don't consume enough fruits and vegetables, while the majority of healthy children consumed enough fruits and vegetables. There was a significance effect between children who choose their own food and consumption of fruits and vegetables ($p=0.001$). There was significance effect between children who take meals to school and consumption of fruits and vegetables ($p=0.003$), children who packed to school consume more fruits and vegetables, compared to those who did not. Children who were allowed to consume unhealthy food did not have enough intakes of both fruits and vegetables, compared to those children who were not consuming unhealthy foods.

Table 4. Association between Awareness of Nutrition Fact Label and Socio-Demographic Characteristics

Variable	Awareness of Nutrition Fact Label (%)		p Value
	Yes	No	
Gender			
Female	70.5	61.2	NS*
Male	29.5	38.8	
Age of parents			
18-30	35.3	2.1	0.001
30-45	43.1	30.6	
>45	21.6	67.3	
Marital status			
Married	98	85.7	NS*
Divorced	2	12.2	
Widowed	0	2.1	
Education level			
Graduate	78.5	46.9	0.003
Undergraduate	7.9	30.6	
High school	13.8	22.5	
Work status			
Yes	64.7	44.9	0.047
No	35.3	55.1	
Family income (KD/mo)			
200-<1000	17.6	28.6	NS*
1000-2000	76.5	65.3	
>2000	5.9	6.1	
No. of children			
1-3	66.6	32.6	0.001
4-6	21.6	63.3	
>6	11.8	4.1	
Age of children			
2-10	64.7	42.9	0.040
11-18	35.3	57.1	
Children health disorder			
Yes	15.7	24.5	NS*
No	84.3	75.5	
Shopping location			
Cooperative	62.8	59.2	NS*
Supermarket	33.3	26.5	
Both	3.9	14.3	
Allowing children to choose their food			
Yes	76.5	91.8	0.036
No	23.5	8.2	
Allowing children to eat unhealthy food			
Yes	52.9	75.5	0.019
No	47.1	24.5	

* NS=not significant

Table 5. Relationship between Some Socio-Demographic Characteristics and Consumption of Enough Fruits and Vegetables

Variable	Consumption of Enough Fruits and Vegetables				p Value
	Fruits	Vegetables	Both	None	
Age of parents					
18-30	20.0	15.6	80.0	13.9	0.017
30-45	50.0	34.4	0.0	37.2	
>45	30.0	50.0	20.0	48.9	
Education level					
Graduate	70.0	56.3	100.0	60.5	NS*
Undergraduate	20.0	15.6	0.0	23.3	
High school	10.0	28.1	0.0	16.2	
Work status					
Yes	50.0	56.3	80.0	53.5	NS*
No	50.0	43.7	20.0	46.5	
Family income (KD/mo)					
200-<1000	35.0	15.6	20.0	23.3	NS*
1000-2000	60.0	75.0	80.0	72.1	
>2000	5.0	9.4	0.0	4.6	
No. of children					
1-3	55.0	50.0	80.0	44.2	NS*
4-6	45.0	40.6	0.0	46.5	
>6	0.0	9.4	20.0	2.3	
Children health disorder					
Yes	0.0	6.3	0.0	41.9	0.001
No	100.0	93.7	100.0	58.1	
Pack for school					
Yes	55.0	25.0	0.0	37.2	0.003
No	35.0	71.9	60.0	60.5	
Sometimes	10.0	3.1	40.0	2.3	
Allowing children to choose their food					
Yes	95.0	87.5	20.0	83.7	0.001
No	5.0	12.5	80.0	16.3	
Allowing children to eat unhealthy food					
Yes	65.0	62.5	0.0	72.0	0.017
No	35.0	37.5	100.0	28.0	

* NS=not significant

Association of the Source of Nutrition Knowledge with Shopping Awareness

The relationships between the source of nutrition information and different traits of interest are shown in Table 6. There was no significant effect of the source of nutrition information and the most

important information in the nutrition fact label from the parents' point of view. Also, results showed a non-significant relationship between the source of nutrition information and the purchasing of ready to eat meals, most eaten food groups, packing food to school, allowing children to choose their food, parents guiding their children, or allowing children to consume non-healthy food.

Table 6. Relationship between the Source of Nutrition Knowledge and Shopping Awareness

Variable	Source of Nutrition Knowledge			p Value
	Media	Books and Doctors	Friends and Family	
Most important information in the nutrition fact label				
All	1.50	16.0	0.0	NS*
Calories	26.9	16.0	50.0	
Fat	17.9	12.0	25.0	
Sugar	17.9	16.0	0.0	
Salt	3.0	4.0	0.0	
None	32.8	36.0	25.0	
Shopping for nutrient claim				
All	4.5	8.0	50.0	0.022
Cholesterol-free	3.0	0.0	0.0	
Low fat	46.4	44.0	25.0	
Low sugar	3.0	0.0	12.5	
Natural	7.4	4.0	0.0	
None	23.9	36.0	12.5	
Organic	5.9	8.0	0.0	
Other	5.9	0.0	0.0	
Knowledge of food ingredient label				
Yes	46.3	64.0	87.5	0.044
No	53.7	36.0	12.5	
If yes, which ingredient				
Additives	40.3	72.0	37.5	0.001
Allergy components	5.9	0.0	25.0	
Sugar	3.0	0.0	25.0	
None	50.8	28.0	12.5	
Purchasing ready to eat meals				
Yes	59.7	60.0	37.5	NS*
No	40.3	40.0	62.5	
Most eaten food groups				
All	3.0	8.0	0.0	NS*
Dairy	5.9	20.0	25.0	
Fruits and vegetables	9.0	8.0	12.5	
Grains	16.4	8.0	37.5	
Meat	65.7	56.0	25.0	
Pack for school				
Yes	34.3	28.0	62.5	NS*
No	61.2	60.0	37.5	
Sometimes	4.5	12.0	0.0	
Allowing children to choose their food				
Yes	83.6	84.0	87.5	NS*
No	16.4	16.0	12.0	
Parents guiding children				
Yes	95.5	100.0	100.0	NS*
No	4.5	0.0	0.0	
Allowing children to consume unhealthy choices				
Yes	62.7	60.0	87.5	NS*
No	37.3	40.0	12.2	
*NS=not significant				

However, there was a significance effect of the source of nutrition information and knowledge of food ingredient label - with food additives being the most important ingredients of concern. There were significant relationships between consumption of junk foods, soft drinks, and juices and “where do you get your nutrition information” ($p=0.032$), which means that the parents who allow their children to consume junk foods and sugary drinks get their nutrition information from the media. Meanwhile, parents who do not allow their children to consume junk foods get their nutrition information from reliable sources such as books and family doctors and trusted media sites. What is presented in the media in this regard has a powerful impact and the highest influence on children and their parents.

DISCUSSION

The results confirm that the knowledge level of Kuwaiti parents is considerably limited and needs improvement.⁵ One of the findings is that younger parents generally had more nutritional awareness than older parents, although a large percentage still did not pack a healthy lunch for their children to school. Instead, the children were given pocket money and left to select what they wanted from the school's canteen; which, according to some parents, consisted of the fast-food type and unhealthy food choices. Some of the parents had a successful influence on their children and were able to feed their children what they considered to be “enough” fruits and vegetables. Other parents were allowing their children to consume as much junk food items as they please only because they do not consider themselves to be “well-rested” enough to deal with their children's desires. Several parents explained that they understand these foods were harmful, but they did not want to deprive their kids from foods that other children are consuming.

One of the findings is that out of the 100 parents who participated and were questioned about their kid's health status, 20% parents mentioned that their kids were suffering from nutrition-related disorders such as obesity, hypercholesterolemia, cardiovascular diseases, diabetes, and food allergies.

Age is a significant factor in determining the level of knowledge and nutritional awareness,¹⁸ which this study has confirmed. Older parents who were 45 years and above have nutritional knowledge that can be linked to tradition and culture. Only two elderly parents had some idea about “modern” nutrition from interacting with their grandchildren and keeping up with new information through the media. As for the younger parents, they had a higher level of education, most of which were university graduates, and a higher-level of nutritional awareness. They read food labels and could identify several aspects of food and chemical additives. They also chose to stay away from the supposedly dangerous chemicals such as monosodium glutamate (MSG). Many of them were up-to-date and were able to discuss recent controversies surrounding nutritional information and latest findings. When questioned about their source of nutrition information and knowledge, approximately 54% of both parents of all ages stated that they got most of the information from the media such as: Instagram, WhatsApp broadcasts, and YouTube videos. Furthermore, social media has the upper hand in spreading the nutritional awareness

in Kuwait, though there are both advantages and disadvantages to this phenomenon.¹⁹ The people using these social media tools are giving out straightforward and clear information to other users and viewers. These tools allow people to access information in a faster manner, which is demanded, in this modern age of the technological revolution. Unfortunately, people can always give nutritional advice whether they are eligible and accredited or not.^{20,21} There is not sufficient awareness and knowledge in the Kuwaiti society about accreditation and people have a preference for fast results; therefore, accepting any information from anyone and naively assuming that the source has enough credibility to go on posting such information about nutrition on the internet. Visual images posted on social media also have shown to be a strong influence in society by promising false fast results and gaining many followers.²² The rest of the parents refer to books, friends, or family doctors for their information due to the prevalence of medical and nutritional disorders in either the parents or their children. Additionally, a large proportion of parents who are working are susceptible to buy ready-to-eat meals than the non-working parents. Working parents state that they do not have enough time to prepare food for their children, thus resorting to opt for the easier, more convenient options regardless of their lack of healthy selections. Due to their free time, non-working parents, especially mothers, take the time to prepare homemade meals for their children despite that these meals are not necessarily healthy. Also, non-working parents have the time to prepare lunch boxes for their children to school - while working parents usually are content with giving their children pocket money. The components of the packed lunch boxes are usually a cheese sandwich, some nuts and a small container of milk or juice. The addition of fruits and vegetables are scarce in their children's menu for the school lunch boxes. Parents of ages ranging from 18-45 years were shown to pack food for their kids to school more frequently than older parents.

Fruits and vegetables are important for children's health and their growth by providing their bodies with essential nutrients such as vitamins and minerals.^{7,10} The interviewed parents did not fully understand the importance of the serving sizes for fruits and vegetables and stated that their children consume a subjective “enough” each day. One apple and one potato could be enough in the parents' understanding and this is not sufficient at all according to choosemyplate.gov (USA) - which states that half of the plate should be filled with a broad selection of fruits and vegetables.^{23,24} During the interview, five of the parents mentioned that their children were obese and that they do not consume any fruits and vegetables. Furthermore, the Kuwaiti children's consumption of fruits and vegetables is not adequate, and the serving sizes and portions of food consumed by their children are worryingly unknown to the parents. Most parents, especially working parents, were not aware of what their children consume and were estimating their portion sizes for the questionnaire.

Many working parents were shopping for ready-to-eat meals. They explained that they do not have enough time to cook for their children and there is a caregiver that cooks for their children instead. They also explained that they could not be sure that their kids are consuming the caregiver's food; therefore, they would buy the ready-to-eat meals to encourage kids to eat. Ready-to-eat

meals are usually processed packaged meals such as frozen pizza, frozen nuggets, packaged soups, ready to use syrups.²⁵ Similarly, they include junk foods such as sugary juices, fizzy drinks, wrapped sweets, chips, cookies, and chocolates.²⁶ Those ready-to-eat meals are inappropriate for children to thrive on due to many health-disrupting affects.^{24,27} For example, foods that we may consider to be healthy can be actually harmful - such as the case of most packaged muesli, which contain soy lecithin, a byproduct of the soybean oil production.²⁸ Soy lecithin, which is used to bind the various food ingredients together, was found to have side effects such as changes in weight loss and gain, loss of appetite, occasional nausea, dizziness, vomiting and confusion.²⁸ Furthermore, most coloring agents are harmful to children according to a review that has been done to evaluate the effect of artificial coloring on children and whether if such has a harmful effect on children? It was found that these substances can bind to human serum albumin and cause health problems. Artificial dyes in foods were found to cause attention deficit hyperactivity disorder in children - when compared to natural coloring.²⁹ Consequently, several studies showed evidence that children's consumption of processed foods can and will eventually result in behavioral problems.³⁰ Finally, there was no relationship between the level of family income and the susceptibility to buy ready-to-eat meals in this study.

To the best of our knowledge, this study is the first to explore aspects of parents' behavior in relation to their children nutrition in Kuwait. Further expanded studies are recommended in this area, which would include wider segments of the population in the country. Emphasis of future studies would be on enhancing parents' awareness and knowledge of nutrition and on the significance of following healthy dietary habits and lifestyle for themselves and their growing children.

CONCLUSION

The knowledge and comprehension of nutritional information of parents highly influences their children's consumption of food choices such as: nutritious foods, and or non-healthy food items - hence shaping their food eating patterns, food choices, as well as their current and future health. Many parents' grocery shopping habits were analyzed along with their nutritional knowledge and their children's eating patterns for examining the influence of parent's nutritional knowledge on their children's health in the Kuwaiti society. Both male and female parents of Kuwaiti nationality, were interviewed in several different supermarkets and cooperatives for this study and results were analyzed with the use of credible statistical tools. Most parents were found to practice negative shopping habits, whether they had some nutritional information or not, depending on several influences such as age, working hours, and the time and level of effort they can devote. Many do not pack lunches for children to school and many indulge in buying ready-to-eat meals for their household. Several parents showed knowledge in the nutrition field, especially those that were in the younger age ranges and practiced healthy habits such as cooking for their children themselves, watching what their children eat?, packed healthy lunches to school and showing the children good examples. Both of those who were knowledgeable

and those that had scarce knowledge in nutrition received their information mainly from the media. These findings underline the need for more awareness of nutrition among parents and an emphasis on the role of healthy nutrition and lifestyle in disease prevention. Different public health approaches can be employed to enhance the significance of sound nutrition and its positive effect on general health. Nowadays, the available electronic media can be the vehicle for enhancing such a relationship and for providing credible and scientifically-based information. This study opens the door for many large scale and more comprehensive studies in this important-to-all area. Such studies may better be longitudinal, rather than being cross sectional - to allow for analysis of the health of children in relation to their prolonged food choices.

LIMITATIONS

This study was primarily limited by the method of data collecting. Self-reporting was the main method instead of actual food label reading test and visual examples for food serving sizes. When parents were questioned if they included processed foods, they reported in the negative - but when given examples, the parents changed their answers. Most parents were mainly shopping for ready-to-eat meals and only a few had healthy baskets with fresh produce. Another possible improvement to the study could have been interviewing the participants in a quieter corner setting, which could elicit greater information regarding the participant's knowledge and attitudes. Many parents were in a hurry to shop and to go back to their homes - thus answering the questions vaguely and quickly. Some parents' reports were false, and the cart they pushed around in the grocery store did not evidence what they stated. They had mostly ready-to-eat meals and junk food items while stating their kids love consuming fruits and vegetables and claimed that they witnessed their children consuming healthy food. Also, it would have been desired to interview the children of the participating parents. The number of subjects of this study is not considered to be large; however, such is considered satisfactory with experienced time constraints. Meanwhile, being the first study of its kind in Kuwait, there can be further studies that explore several perspectives and the many interchanging and interfering factors.

AUTHORS' CONTRIBUTIONS

This work was carried out as a capstone project when the first 4 authors were senior students in nutrition at the Department of Food Science and Nutrition, College of Life Sciences, Kuwait University, Kuwait. Eman Al-Awadhi searched for relevant recent studies and reviewed the different versions of this manuscript. Farouk El-Sabban supervised the capstone project, coordinated all efforts, and edited the final version of this manuscript. All authors read and approved of this manuscript for publication.

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CONFLICTS OF INTEREST

All authors declare that there is no conflict of interest in conducting this study or in publishing its results.

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Mini Review

Avianomics: The Beginning at the End

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PREFACE

The research-teaching nexus is the pinnacle of academic activity. As a scientist and educator, my overall objective is to give students access to cutting-edge research and help them develop high order inquiry skills. In addition, as research and thesis writing frequently involves the development of new complex reading skills associated with comprehension and synthesis of a tremendous volume of information, along with in-depth critical analysis, evaluation, and elegant academic writing style, I decided to assign this editorial to my 2020-Biochemical Nutrition graduate students. As my students have diverse educational and cultural backgrounds and have been exposed to a variety of tech-based learning, we decided to summarize here recent advances in omics research in avian species to facilitate the discussion by asking new questions, which may help open new vistas for future investigations. By following the “scaffolded” approach, my students highlighted progress in Transcriptomics (Komp M and Bowie R), Proteomics (Tabler T and Lee T), Kinomics (Hernandez RM and Zuo B), Epigenomics (Ferver A), Metabolomics (Maynard C and Mullenix G), and Microbiomics (Teyssier JR and Bodle B). I would like to thank my students for their motivation, dedication, determination, perseverance, connection, consistency, and support. I would also like to thank AFTNS-OJ for inviting me to write this editorial and I hope by getting my students involved would promote their curiosity, help them understand complex questions, explore more sources, stimulate their independent thinking, and create research- and question-mindsets.

AVIAN TRANSCRIPTOMICS

The transcriptome of an organism, cell, or tissue refers to the complete set of ribonucleic acid (RNA) species or gene transcripts that are being transcribed at a certain time point. Transcriptomic research aims to compare cells or tissues under defined conditions or disease states to identify changes in gene expression; therefore, giving us a better idea, of which functions different coding or non-coding genes might have, and a better understanding of how they contribute to the phenotype of individuals and their functional adaptations during their lifetime.^{1,2}

There are two main techniques in the field of transcrip-

tomics: microarrays and RNA sequencing. Microarrays are used to measure predetermined sequences, whereas ribonucleic acid (RNA) sequencing captures all sequences through high-throughput sequencing (whole-transcriptome shotgun sequencing).³ These techniques have allowed for a greater understanding of how gene expression changes and identifies trends that cannot be detected by more targeted assays.⁴

In avian research, transcriptomics has had major implications for our understanding of avian diseases, nutrition, growth, and well-being. The use of transcriptomics is also paving the way for future research opportunities and technology developments that will bridge the gap between traditional avian research and ge-

nomics and stimulate more interdisciplinary research.

Transcriptomics in Health and Disease

By using transcriptomics to compare gene expression profiles in healthy and diseased individuals we can attain a greater knowledge of what parts of the genome are or are not being regulated during disease and observe structural alterations, such as mutations. A particular interest in understanding what makes a species resistant or susceptible to a certain infectious disease has further led to several comparative immuned biological studies, which has provided great advancement in the field of immunology. For instance, the use of dual RNA-seq of host and pathogen has led to studies of host and parasite co-evolution. Transcriptomic analysis of chicken lungs characterized the transcriptomic profile of chicken lungs infected with the parasite, *Pasteurella multocida*, and provided valuable information to understand host responses. The study identified an avian *P. multocida* serogroup A strain (PmQ) showing high lethality to chickens and a bovine *P. multocida* serogroup A strain (PmCQ2) with no lethality to chickens.⁵ Analyzing the hardier gland, trachea, and lung tissues, Lamont's group identified several markers associated with Newcastle disease.⁶ Similarly, by using RNA-seq, several differentially expressed genes were identified in woody-breast affected chickens when compared with unaffected counterparts.⁷ Marchesi and co-workers identified several genes associated with white striping in broiler chickens.⁸ Berri's group performed a muscle transcriptome analysis and revealed several biomarkers associated with meat defect in chickens.⁹ By using RNA-seq, several osteochondral genes have been shown to be altered in bacterial chondronecrosis with osteomyelitis (BCO) in chickens.¹⁰

Transcriptomics in Well-Being

Transcriptomics has the ability to play a key role in many aspects of avian welfare. For example, a transcriptome analysis reveals that stocking density affects the expression of genes involved in several metabolic pathways such as glycolysis, proteolysis, immune stress, muscle development, cell adhesion, matrix, and collagen.¹¹ Several studies showed different transcriptome profiles in various chicken tissues in response to high ambient temperature.¹²⁻¹⁴ They identified Angiopoietin-like-4 (*ANGPTL4*) gene as a candidate for the improvement of heat tolerance in chickens.

Transcriptomics in Growth, Development and Feed Efficiency

Feed efficiency is a key agricultural and economic trait. Transcriptomic technology could allow for a deeper understanding of residual feed intake among other nutrition related components. A recent study suggested that using transcriptome architectures based on high-quality RNA-Seq data reveals 41 differentially expressed genes associated with residual feed intake. These genes play a role in digestibility, metabolism, stress response, and energy homeostasis.¹⁵ Recently, Yang Lei and co-workers identified key genes and pathways associated with feed efficiency in native chickens.¹⁶ Using high and low feed efficient birds, Kong et al¹⁷ identified several key genes in breast muscle that are involved in anabolic pathways. By comparing the transcriptome between pigeon ovaries before and after ovulation, Xu et al¹⁸ found that the expression of several genes is modulated during different stages of ovulation. By study-

ing six avian species, Wright et al¹⁹ found higher gene divergence on the Z chromosome compared to autosomal chromosomes.

AVIAN PROTEOMICS

Proteomics, in its simplest definition, is the study of the proteome, which encompasses the expression of whole protein profiles in a biological system. Marc Wilkins, in 1994, is credited for developing the concept and coining the term "proteome". Its application today in regard to poultry is, but not limited to, studying the cell, tissue, or organ proteins that are expressed (measured and compared), have protein-protein interactions, or are structural components that may impact bird health, well-being, and growth. In addition to improving bird welfare, its application has extended to improving meat quality to the consumer.

Several techniques are frequently used in proteomics including 2-hybrid systems, 2-dimensional gel electrophoresis, and mass spectrometry. Systems biology is a scientific approach that takes into account the complex relationships among and between genes and proteins and determines how all of these interactions come together to form a functional organism. Proteomic tools can simultaneously probe the properties of numerous proteins and thus are a great aid to the emerging field of systems biology, in which the functional interactions of numerous proteins are studied instead of studying individual proteins as isolated entities. In the field of avian biology, proteomics has been used to study different processes from the development, growth, and function of organs and systems to the interactions of infectious agents and the altered states that they induce in their hosts.

Proteomics in Health, Disease and Meat Quality

The following studies have helped elucidate protein changes involving poultry disease and stress such as ammonia stress,²⁰ ascites,²¹ bacterial, protozoa, and viral infection,²²⁻²⁴ femoral head necrosis,²⁵ woody breast,²⁶ and sudden death syndrome.²⁷ The selection of broilers for high growth performance has resulted in an increase in the occurrence of muscle myopathies. The most common are white striping and woody breast myopathies, which have been estimated to cost the U.S. industry \$200 million or more.²⁸ Work by Kuttappan et al²⁸ helped elucidate that protein metabolism and protein translocation (141 involved proteins) are important contributors to these myopathies. Another incidence is the pale, soft, and exudative (PSE) syndrome that reduces color, water holding capacity, and quality of poultry meat, which deters consumers. Xing et al²⁹ identified proteins related to the glycolysis pathway, calcium signaling, and molecular chaperones that are integral in PSE syndrome. Tenderness is an important – possibly the most important – driving force for consumer purchase decisions. Mekchay et al³⁰ showed three protein spots that were correlated with shear force, play a role in the glycolytic pathway, and are closely related to tenderness. Other meat quality factors like water holding capacity³¹ and flavor^{32,33} have been evaluated for protein biomarkers to improve these areas. These studies not only helped to better understand the protein mechanisms but identified biomarkers for subsequent development of target strategies to reduce or alleviate these issues.

A popular strategy in regulating the host immune system is through feeding probiotics. Luo et al³⁴ offered *Enterococcus faecium* to broilers and identified 42 intestinal mucosal proteins related to metabolism, immune and antioxidant systems.

Proteomics in Well-Being

Heat load is one of the most challenging stressors to poultry from its adverse effects on growth, gut health, well-being, and mortality. Intestinal health and function are paramount to achieving efficient feed utilization, growth, and welfare. O'Reilly et al³⁵ determined the effects of microbial challenge on broiler intestinal proteome.³⁵ They found that the levels of cytoskeleton³⁵ proteins increased over time in the small intestine. Microbial challenges, however, reduced the expression of Villin-1.35 Tu et al³⁶ and co-workers performed proteomic analysis on the hypothalamus of heat-stressed broilers and identified 114 proteins that are mainly involved in cellular processes, metabolism, transport, and cellular defensive response against oxidative stress and toxin export and delivery.

Proteomics in Growth, Development and Feed Efficiency

Proteomics has not only allowed a better understanding of changes in protein processes but has introduced a new era of selecting broiler genetic lines for superior performance. Kong et al³⁷ selected higher feed efficiency birds from a standard flock and demonstrated that birds having a higher feed efficiency had greater breast muscle mitochondria protein expression caused by higher mitochondrial function and oxidative phosphorylation. Phongpa-Ngan et al³¹ separated broilers that had a fast or slow growth rate from the same flock and found broilers with a faster growth rate had a unique protein profile in muscle tissue. In the past decade, the selection of broilers for improved performance has been accompanied by excessive body fat. Wang et al³⁸ identified 33 different proteins that are related to biological oxidation, cell proliferation, cytoskeleton, lipid metabolism, chaperones, protein synthesis, and signal transduction between fat and lean broilers.

AVIAN KINOMICS

Kinomics is mainly used to study the abundance, activity, substrate specificity, phosphorylation status, and other characteristics of kinases and phosphatases in cells or tissues. Protein kinase refers to a class of enzymes that modifies other proteins by chemically adding phosphate groups to them. The protein phosphorylation is one of the important protein post-translational modifications, which plays key roles in the metabolism, transcription, cell cycle regulation, apoptosis, movement, and other cellular processes of most eukaryotic cells.³⁹ Studies have shown that more than 30% of proteins are phosphorylated at any time in cells.⁴⁰ In the human kinome, 518 protein kinases were identified, and 244 kinases were found to be related to the occurrence of diseases through chromosome mapping and other means.⁴¹ Phosphorylation and dephosphorylation are like a molecular switch that could regulate the activation and inactivation of certain proteins. Peptide or protein array screen coupled with mass spectrometry (MS) is widely applied to determine phosphorylation because of the convenience and sensitivity, and proteomics has high-throughput

potential and requires no knowledge of sequence preference of the kinase.^{42,43}

Although kinomics is an emerging powerful technology at large scale, very limited studies have been conducted in avian species.

Kinomics in Health and Disease

By using a chicken-specific kinome array, Kogut and colleagues showed that *Salmonella modulates* host immune signaling pathways in the cecum to establish a persistent infection.⁴⁴ Specifically, they showed that the response is characterized by alterations in the activation of T-cell signaling mediated by the dephosphorylation of phospholipase c-γ1 (PLCG1) that inhibits NF-κB signaling and activates nuclear factor of activated T-cells (NFAT) signaling and blockage of interferon-γ (IFN-γ) production through the disruption of the JAK-STAT signaling pathway.⁴⁴ The same group identified that AMP-activated protein kinase (AMPK) and mechanistic target of rapamycin (mTOR) are key sensors and regulators of immunometabolic changes during *Salmonella infection* in chickens.⁴⁵

Kinomics in Well-Being

Napper and co-workers used the global cellular kinase approach to characterize kinome response within the breast and thigh muscles of heat- and cold-stressed chickens.⁴⁶ In the breast, both cold and heat stress activated calcium-dependent metabolic adaptations. Also within the breast, but specific to cold stress, the activation of ErbB signaling as well as dynamic patterns of phosphorylation of AMPK were observed. In the thigh, cold stress activates innate immune signaling and transforming growth factor-beta (TGFβ), however, heat stress-activated pathways are associated with protein and fat metabolism through adipocytokine and mTOR signaling.

EPIGENOMICS

Epigenomics is the study of the complete set of epigenetic (modifications that alter gene expression that cannot be attributed to the modification of the primary deoxyribonucleic acid (DNA) sequence) modifications on the genetic material of a cell, known as the epigenome. DNA methylation and histone modification are among the best-characterized epigenetic processes.⁴⁷ Several approaches, including histone modification assays, Chip-Chip and Chip-Seq, DNA methylation assays, bisulfite sequencing, and chromatin accessibility assays, are used.

Epigenomics in Health and Disease

Deoxyribonucleic acid methylation has been investigated in relation to disease states in chicken, specifically Marek's disease, comparing two lines, Fayoumi and Leghorn. This study confirmed that variation in DNA methylation leading to changes in gene regulation likely confers disease resistance and it was observed that DNA methylation was highest in internal exons.⁴⁸ Immune related genes, such as TLR4, was found to be both differentially methylated and expressed in the two lines and further demon-

strates the potential regulatory role of DNA methylation in the control of gene expression. Marek's disease infection of two lines, with differing resistance, was also analyzed for histone post-translational modifications (HPTMs). Differentially enriched regions were seen between the susceptible and resistant lines, with the HPTM profile being modulated after infection around immune response genes.⁴⁹⁻⁵¹ Epigenetic modifications were also observed in the immune underlying mechanisms in chicken susceptible to *Salmonella enteritidis*.⁵²

Epigenomics in Well-Being

Epigenetic studies have been conducted in heat-stressed chickens and showed alterations in the methylation level of CpG site in the promoter of the brain-derived neurotrophic factor (*BDNF*) gene. Modifications of histone H3 lysine 9 (*H3K9*) and methylation of histone H3 lysine residue 27 (*H3K27*) in the promoter of hypothalamic brain-derived neurotrophic factor (*BDNF*) were also observed during thermotolerance acquisition on day 3 post-hatch.^{9,53} In addition to postnatal experience and genetics, it has been reported that chicken behavior can be modulated by epigenetic mechanisms.⁵⁴

Epigenomics in Growth, Development and Feed Efficiency

It has been shown that environmental and nutritional factors can influence embryonic development and the adult phenotype, at least partially, *via* epigenetic mechanisms and adaptation. For instance, Tzschentke and Basta have shown that temperature variation during the prenatal period influences hypothalamic neuronal thermosensitivity during the postnatal stage.⁵⁵ Similarly, nutritional programming affects offspring phenotypes. Rao et al⁵⁶ showed that 4 week-old chicks from mothers fed low-protein diets had a higher body and breast muscle weights confirming that maternal nutrition can affect offspring phenotypes.

METABOLOMICS

Metabolomics is the emerging field of metabolome analysis that characterize, identify, and quantify metabolites in biological (cell, tissues fluids) samples. As metabolites play a crucial role in the maintenance and growth of organisms, they are considered as the "canaries" of the genome and the intermediate phenotypes. Their application in livestock in general and poultry, in particular, might become a cornerstone for the "next-generation phenotyping" approaches. An increasing number of studies have integrated metabolomics in poultry.

Metabolomics in Health and Disease

Le Roy et al⁵⁷ established a high-resolution proton nuclear magnetic resonance-based metabolic atlas and identified several metabolites in different tissues in chickens. By using ultra-performance liquid chromatography/tandem mass spectrometry, Aggrey's group identified several metabolites associated with fatty acids metabolism and beta-oxidation in *Eimeria acervulina*-infected chickens.⁵⁸ Ma and coworkers have shown that *Salmonella enterica* infection altered the intestinal metabolome in chickens.⁵⁹ Dridi's group identified

a total of 108 known metabolites in chicken breast, with 60 having significant mean intensity (42 higher and 18 lower) in woody breast-affected compared to unaffected muscles.⁶⁰ These differentially abundant-metabolites were associated with purine nucleotide degradation and *de novo* biosynthesis, sirtuin signaling pathway, citrulline-nitric oxide cycle, salvage pathways of pyrimidine DNA, IL-1 signaling, iNOS, Angiogenesis, PI3K/AKT signaling, and oxidative phosphorylation.⁶⁰

Metabolomics in Growth, Development and Feed Efficiency

Mignon-Gasteau group showed that ileal, caecal, and serum metabolome explains approximately 75-76% of the variability of the apparent metabolizable energy and digestive efficiency in chickens.⁶¹ Analyzing serum metabolome, Metzler-Zebeli et al⁶² observed a distinct profile between two divergently selected chicken lines for residual feed intake and feed efficiency. Supplementation with Magnolia Bark extract or *Bacillus subtilis* modulates the intensity of several intestinal metabolites associated with amino acids, fatty acids, peptides, and nucleosides.⁶³ Peng and co-workers have shown that 39 and 68 metabolites were significantly changed from E14 to E19 and from E19 to hatch, respectively in chicken embryos, indicating a potential role of the metabolome in chicken development.⁶⁴ Similarly, Wu et al⁶⁵ studied the hepatic metabolic changes during postnatal liver maturation in breeder roosters and identified several differentially abundant metabolites involved in carbohydrate, protein, amino acid, lipid, cholesterol, nucleic acid, and vitamin metabolisms.

MICROBIOMICS

The microbiome is defined as a characteristic microbial community in a reasonably well-defined habitat, which has distinct physicochemical properties as their theater of activity.⁶⁶ The study of this microbial community is known as microbiomics. Until early 2000, the study of the microbiome was only relying on the culturable microorganism, which represents a very low portion of the bacterial population as low as 1%. In the microbial research field, the two last decades have been marked by the development of high-throughput DNA-based sequencing methods, new bio-informatics developments, and analysis methods. That methodological progress has allowed the detection and quantification of unculturable bacteria and access to an important amount of data on genome diversity. The study of the microbiome has revealed bacteria to be implicated in numerous functions for the human organism, but the microbiome research has also a wide range of applications in food science, biotechnologies, and agriculture.⁶⁶

Microbiomics in Health and Disease

As described above, gut health, function, and integrity are essential for the overall well-being and health of birds. Consequently, the gut microbiota, which contains tremendous numbers of bacterial species, has recently been extensively characterized in some avian species including chickens, turkeys, and ducks.⁶⁷⁻⁶⁹ The influence of viral and bacterial infections on gut health, integrity, and homeostasis have been also studied. For instance, Experimental infection of young chickens with H9N2 virus caused alterations in the intestinal

microbiota composition with increased phylum Proteobacteria.⁷⁰ In a study conducted by Li et al,⁷¹ in addition to increased phylum proteobacteria, Firmicutes was decreased in H9N2 virus-infected chickens. Hird and colleagues reported that the cloacal microbiome in wild ducks is specie-dependent and varies by influenza A virus infection status.⁷² Similarly, the effect of Newcastle and bursal disease viruses on avian microbiota has been investigated.^{73,74}

Microbiomics in Growth, Development and Feed Efficiency

Several studies investigated the effect of diet on growth and gut microbiome in regard to diversity and composition. The inclusion of xylanase and β -glucanase enzymes in diet enhance the growth of lactic acid bacteria, which adhere to the gut epithelium and compete with pathogens for its colonization while decreasing lumen viscosity.⁷⁵ Supplementation with phytase promotes the abundance of *Aeromonadaceae* and *Flavobacteriaceae* in the crop, and *Lactobacillus sp.*, *Clostridium leptum* and *Enterococcus sp.* in the ileum and enhances growth performances in chickens.⁷⁶ Costa et al⁷⁷ have shown that the administration of different antibiotic growth promoters induces specific changes in the cecal microbiota in broilers. Wang et al⁷⁸ showed that probiotics modulate gut microbiota and improves meat flavor in chickens. By performing 16S ribosomal ribonucleic acid (rRNA) sequencing, Jurburg et al⁷⁹ monitored the chicken fecal microbiome at different ages and identified three successional stages characterized by dominant *Streptococcus* and *Escherichia* taxa from 1 to 3 d post-hatch, followed by *Lachnospiraceae* and *Ruminococcus*-like species from 4 to 10 d post-hatch, and a final stage with dominant *Candidatus Arthrobacter* and *Romboustia* from day 10 (Figure 1).

CONCLUSION

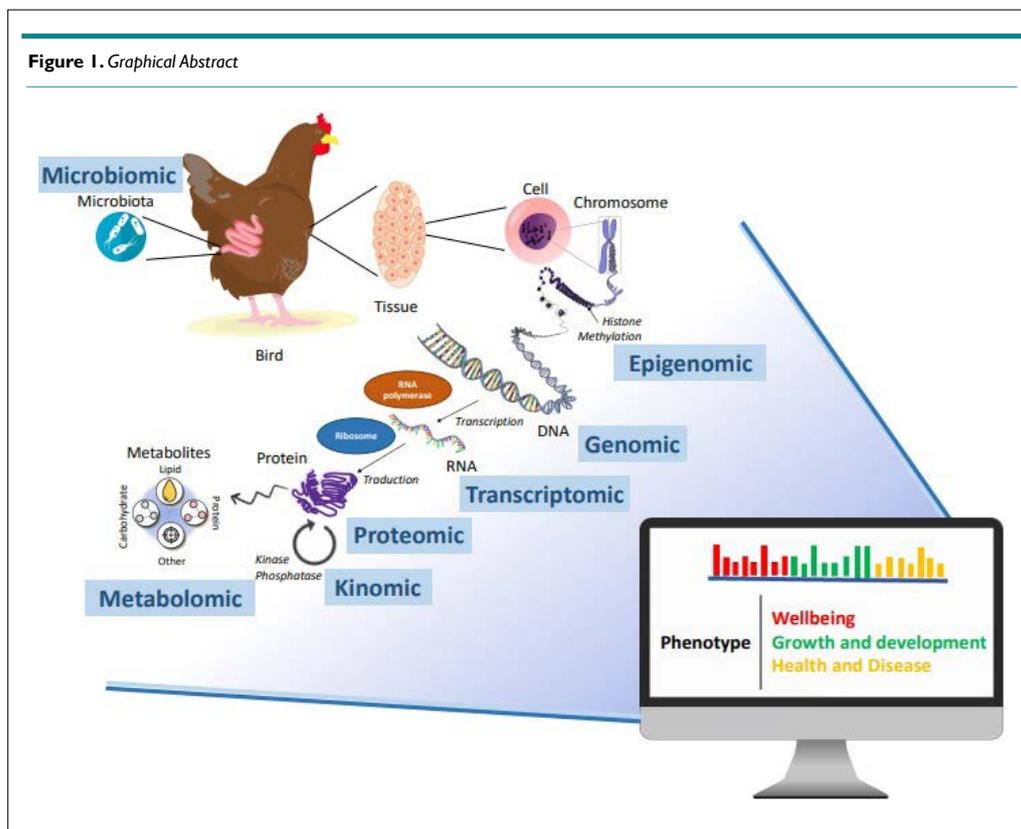
Challenges and Perspectives

From ontogenesis to homeostasis, the phenotypes are shaped by multi-complex interactions and networks between genes, proteins, and microbiome and their interaction with their surrounding environment (nutrition, environment, stress, etc.).

In poultry, multi-omics analysis revolutionized avian researches and revealed unprecedented interesting data. However, exploring the full extent of the abovementioned interactions requires careful considerations of study design to efficiently generate optimal data integration. For instance, past omics studies used a variety of tissues and mixed cell populations to attain the differential expression profile, which might mask the cellular specific information. In the future, integrative single-cell omics is warranted.

Development of portable technology would help omics studies in an on-site field, which would minimize the time between harvesting and sequencing, but can also facilitate the workflow in countries where sequencing facilities are scarce or where export of tissues is a hampering factor. If the technology of such is incorporated, rapid identification of the virus or pathogens could be achieved, which in turn could help to minimize the spread and outbreak of infection.

Despite their descriptive nature due to lack of mechanistic studies, the multi-omics studies have the potential to change



the future of poultry production and sustainability from dietary, environmental, management, and breeder guidelines by identifying key markers and their networks (gene, protein, metabolite, etc.) for precision selection and personalized nutrition approach under appropriate conditions and adaptations.

CONFLICTS OF INTEREST

All authors declare that there is no conflict of interest in conducting this review or in publishing its results.

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