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Original Research Article

EVALUATION FOR IMPACT OF CLIMATE CHANGE ON WHEAT (*TRITICUM AESTIVUM* L.) GRAIN QUALITY AND YIELD TRAITS

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Abstract: *Climate change is increasing stress on agricultural production, notably in developing nations where crop yields are critically impacted. Swift changes in climate conditions directly diminish wheat yields and adversely influence key grain constituents such as starch, fibre, protein, amino acids, and essential nutrients. The studies were conducted for six years, from 2017-18 to 2022-23, to understand the impact of changing climate on wheat grain composition and quality. The results indicated that November is the best month for sowing wheat. The post-anthesis drought or less water availability helps the plants accumulate more protein and gluten contents, and starch contents decrease. The quality of the grain, however, is more significantly influenced by the variety of wheat, the type of environmental stress, and the duration and severity of exposure. Faisalabad 08 had the highest protein and gluten contents, while Galaxy 13 had the highest starch contents in D2. Galaxy 13 indicated the highest value of test weight and 1000-grain weight in November.*

Keywords: *climate change; food security; starch content; gluten protein; cereal*

Introduction

Wheat is a cereal grain originally from the Levant region of the Near East and Ethiopian Highlands, but it is now cultivated worldwide. During, 2023 the world wheat production was 785 million tonnes (FAO, 2023), making it the second most-produced cereal after maize. It is adaptable to a wide range of climates and soils, which is why it is grown on more land area than any other food crop. Wheat's ability to be stored for long periods enhances its role as a food security crop. Economically, wheat is a significant trade commodity and affects global markets and economies. Furthermore, wheat straw can be used for various purposes, including roofing thatch, paper production, and as a substrate for mushroom cultivation. The grain itself undergoes numerous processing forms to produce food products essential in many cultures worldwide. Its global significance is evident in its status as a symbol of sustenance and prosperity in various cultures. Wheat is the leading source of vegetable protein in human food, having a higher protein content than other major cereals, maize (corn), or rice. It is a critical ingredient in staple foods such as bread, pasta, noodles, and couscous. The importance of wheat lies in its versatility and nutritional value. Wheat is a staple food in Pakistan, playing a crucial role in the dietary patterns of its population. It is a rich source of carbohydrates, essential for providing energy to the body. Additionally, wheat contains significant amounts of dietary fibre, which aids in digestion and promotes a healthy gut (Dai *et al*., 2023). It also provides proteins; although not complete in amino acids, it can be complemented with other protein sources to fulfill dietary needs. Wheat is also packed with vitamins and minerals, including B vitamins, vital for various metabolic processes, iron for blood production, magnesium for muscle function, and selenium, an important antioxidant. Whole wheat, which includes the bran, germ, and endosperm, retains most nutrients compared to refined wheat products, where bran and germ are removed during processing. Climate change is impacting the nutritional value of wheat significantly (Gupta *et al.*, 1994). Rising CO_2 levels, increasing temperatures, and altered precipitation patterns affect wheat growth, leading to changes in grain composition. Studies have shown that elevated CO_2 levels can increase wheat yield but reduce protein content, affecting the grain's nutritional quality. Higher temperatures can accelerate wheat development, resulting in shorter growing periods and less time for the grain to accumulate nutrients. Changes in rainfall patterns can cause drought stress, reduce wheat quality and yield, or lead to excessive moisture, promoting fungal diseases that can contaminate wheat with mycotoxins. These factors combined threaten the nutritional security provided by wheat, a staple food for billions of people worldwide. Additionally, elevated CO_2 levels can affect wheat growth and development, potentially reducing the concentration of essential minerals like zinc and iron in the grain. These changes impact food security and the economic stability of regions dependent on wheat as a staple crop. An experiment was planned to assess the impact of climate change on wheat quality parameters. Three different genotypes were evaluated by sowing on seven different dates of sowing for six years, and at maturity, quality traits, e.g. starch, protein contents, and gluten were tested.

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Materials and Methods

Three wheat cultivars, Faisalabad-08, Punjab-11, and Galaxy-13, were planted at seven planting dates with ten-day intervals from 1st November to 31st December in the field area of Wheat Research Institute, Faisalabad. The same cultivars with the same sowing pattern were planted for six consecutive years, from 2017-18 to 2022-23. The material was planted under Split Plot Design by placing dates in the main plot and varieties in the sub-plots. The experimental material was replicated three times. The plot size of the subplot was 1.8 meters × 5 meters, accommodating six rows per plot. Each plot was seeded @ 50 kg/ha, and the fertilizer dose was NPK= 125:110:70 kg/ha. The crop was harvested and threshed at maturity using a mini thresher to avoid mixing. The weather data of Faisalabad from November to April was collected from the agro meteorological department. The grains collected were further analyzed for their physicochemical attributes, i.e., Protein, gluten, and starch, using NIR-based kernelized (Sr. No. 214802699 Bruins Instrument, Germany). The collected grains were evaluated for thousand-grain weight using a seed counter (Sr. No. 339 Numigral 2, TRIPETTE & RENAUD, France) and weighing balance(Sr. No. 14297318, GR-200, AND, Japan). In contrast, test weight was assessed by a calibrated digital test weight apparatus used in an ISO-17025:2017 accredited laboratory—the agrometeorological data presented in Table 6.

Results and Discussion

The results indicated that changing climatic conditions also affect the composition of wheat grain. Temperature rise and fall, drought stress, and high-temperature impact protein, gluten percentage, and starch contents. Faisalabad 08 indicated a general upward trend from 2017-18 to 2022-23. There is a noticeable increase in protein levels from 2017-18 to 2022-23, and the highest protein levels were observed on the second date of sowing D2. Punjab-11 exhibited fluctuations in protein levels. The protein levels peak around 2019-20 and decrease slightly in the following years. Similarly, Faisalabad 08 Punjab-11 indicated the highest protein percentage on the second sowing date. Galaxy 2013 shows a consistent decline in protein levels over the years. The highest protein content was 15.1% in 2017-18 and gradually decreased. Faisalabad 08 and Punjab-11 have varying patterns, with Faisalabad 08 showing an overall upward trend while Punjab-11 has fluctuations. Drought conditions profoundly impact plant vitality, affecting growth, grain development, and quality, which in turn has serious repercussions for food security and human health. Research by (Zhao *et al*., 2021) indicated that excessive soil moisture post-anthesis does not favour grain protein synthesis, with optimal protein content observed at moderate soil water levels. Specifically, protein percentages were recorded at 16.7%, 15.09%, and 14.8% for soil water capacities of 45%, 65%, and 85%, respectively (Dong *et al.,* 19991). This suggests that a controlled water deficit may enhance protein formation during the later stages of growth. The study also found that certain protein fractions, such as glutenin and gliadin, and their ratios, increased under drought stress after anthesis, although albumin levels were adversely affected. Complementary findings by (Thungo *et al.,* 2020) revealed that elite bread wheat varieties exhibited increases in average grain protein, gliadin, glutenin, and their respective ratios under terminal drought stress. Conversely, (Singh *et al*., 2012) observed that drought stress in a drought-tolerant wheat genotype decreased total soluble protein and specific gluten fractions while amphiphilic and glutenin/gliadin ratios increased. In contrast, a high-yielding but drought-sensitive genotype showed an increase in overall grain protein and amphiphilic content but a decrease in the albumin/gliadin ratio and specific gluten fractions. Karaman's (2019) research further corroborated these findings, demonstrating enhanced total soluble protein content under drought conditions across various spring wheat varieties. Similarly, (Sattar *et al*., 2020) reported a significant increase in protein content in the bread wheat variety 'Faisalabad-2008' when subjected to drought stress at a critical growth stage. These studies collectively underscore the complex relationship between water availability and protein synthesis in wheat, highlighting the potential for strategic water management to optimize grain protein content under varying environmental conditions (Blumenthal *et al.,* 1995). A recent investigation has highlighted the impact of drought conditions on the protein concentration in various spring wheat strains. Under rainfed scenarios, notable declines in protein levels were observed, with Egan, McNeal, Solano, Vida, Alpowa, Alturas, and Penawawa varieties experiencing average decreases of 4.32%, 6.71%, 7.50%, 7.53%, 6.09%, 4.76%, and 2.63%, respectively, when compared to standard irrigation practices. Furthermore, advanced tandem mass spectrometry techniques have uncovered that prolonged drought stress, characterized by the cessation of watering until severe wilting occurred, led to an increase ranging from 1.3 to 3.8 times in 19 distinct protein spots, as identified in the red spring wheat variety PAN3478, which is typically cultivated under irrigation. The results indicated that gluten contents were also affected by changing climatic conditions. Galaxy 2013 variety consistently produced the highest gluten content across seasons, especially on D2. The highest gluten contents were produced 37.7% during 2019-20. Faisalabad 08 also had the highest gluten contents, particularly in the 2019-20 season, and had produced the highest gluten contents, 36.7%, on the second date of sowing Table 2. Punjab-11 showed varying results, with the highest gluten content occurring on different days in different seasons. Overall, D2 seems to be a critical day for gluten content in these varieties. Punjab 11 produced the highest gluten content 35.0% during the year 2019-20 in D2. Magallanes-Lopez *et al*., 2020 observed a notable increase in grain protein content, which was up to 9.23% higher in plants subjected to drought conditions compared to the control group. Interestingly, it was found that the grain color remained consistent despite the drought stress. Furthermore, Pour-Aboughadareh *et al*., 2020 reported a substantial decrease in the weight of a thousand grains, which was reduced by 44.93% in rainfed durum wheat genotypes when compared to genotypes grown under optimal hydration conditions (which included irrigation at both the heading and mid-filling stages). The estimation of starch contents manifested that the highest starch contents were 59.9% in Galaxy 13 during the year 2017-18 followed by Punjab 11 58.1% during 2022-23. Faisalabad 08 produced the highest starch contents 56.1% during

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2018-19 on the second date of sowing table 3. Sattar *et al.* (2020) documented a decrease in starch content by 10.43%, alongside an increase in gluten content by 15.75%, when spring wheat varieties were exposed to drought stress conditions (50% field capacity for 20 days during the heading stage)..

Table 1: Protein contents of Wheat varieties on different dates of sowing 2017-2023

Protein		D1	D2	D3	D4	D5	D6	D7
Faisalabad 08	2017-18	11	15.8	10.3	13	13.7	12.4	14.8
	2018-19	14.1	15.8	14.4	13.9	14.5	14.7	14.2
	2019-20	15.1	16.3	16	15.3	15	14.3	14.8
	2020-21	13.3	16.6	14.9	14.7	14.5	14.1	14.1
	2021-22	15.37	16.9	15.83	15.83	15.43	15.7	15.77
	2022-23	14.0	16.9	15.6	15.3	14.9	15.1	15.1
Punjab-11	2017-18	12.2	13.8	12.8	12.6	12.6	12.7	12.8
	2018-19	13.6	14.4	12.5	11.9	11.4	11.2	12.1
	2019-20	12.5	16.1	12.2	12.4	13.1	13.1	11.2
	2020-21	13.3	12.2	11.2	12.2	11.7	11.8	11.8
	2021-22	11.9	15.27	12.3	12.6	12.87	11.8	12.93
	2022-23	12.8	15.4	11.0	11.1	12.2	12.8	12.7
Galaxy 2013	2017-18	11.1	15.1	13.3	12.6	13.8	12.8	14.5
	2018-19	13.1	14.4	13.9	13.2	13.9	14.1	14
	2019-20	11.5	13.0	12.9	11.1	11.1	11.4	11.8
	2020-21	12	13.0	11.6	11.7	11.2	11.3	11.6
	2021-22	11.4	12.9	12.2	11.8	11.9	11.97	11.13
	2022-23	11.8	12.5	11.7	11.6	11.4	11.1	11.7

Table 2: Gluten contents of Wheat varieties in different dates of sowing 2017-2023

Gluten		D1	D2	D3	D4	D5	D6	D7
Faisalabad 08	2017-18	20.0	31.0	17.0	25.0	27.0	23.0	29.0
	2018-19	28.7	33.7	29.0	26.7	28.7	30.0	27.3
	2019-20	31.7	36.7	31.7	32.0	30.7	29.3	30.3
	2020-21	26.3	34.0	30.0	30.0	30.0	29.0	28.5
	2021-22	32.3	36.3	33.7	34.3	32.7	33.5	30.0
	2022-23	28.3	34.0	33.7	31.7	30.7	31.0	29.7
Punjab-11	2017-18	21.0	30.0	22.0	22.0	28.0	29.0	28.0
	2018-19	25.0	33.0	26.5	23.7	26.7	28.7	25.7
	2019-20	31.7	35.0	33.0	31.0	26.5	27.0	26.0
	2020-21	25.0	29.0	29.5	30.0	28.0	26.0	27.0
	2021-22	33.3	34.5	33.0	31.7	31.7	34.5	31.3
	2022-23	30.3	34.5	30.5	30.3	29.7	28.7	28.3
Galaxy 2013	2017-18	18.0	35.0	24.0	23.0	26.0	22.0	27.0
	2018-19	23.7	34.7	25.7	23.7	26.0	28.0	26.3
	2019-20	28.3	37.7	30.5	25.3	23.7	23.5	24.3
	2020-21	21.3	36.0	28.5	27.0	24.5	23.0	25.0
	2021-22	29.3	35.3	31.0	31.0	28.0	27.0	27.3
	2022-23	26.7	36.0	28.7	31.0	23.3	25.0	22.5

Table 3: Starch contents of Wheat varieties on different dates of sowing 2017-2023

Starch		D1	D2	D3	D4	D5	D6	D7
Faisalabad 08	2017-18	54.5	55.4	55.2	52.9	51.9	53	51
	2018-19	54.3	56.1	53.4	53.9	53.5	53.6	53.1
	2019-20	53.5	53.2	52.4	53	52.6	53.8	52.9
	2020-21	54.2	55.4	52.8	53.1	53.2	53.4	52.8
	2021-22	51.73	55.6	51.63	53	52.73	51.75	51.37
	2022-23	55.4	55.5	53.5	53.9	53.4	53.1	52.4
Punjab-11	2017-18	54.5	58	53.9	53.8	52.1	52.3	52.1
	2018-19	54.4	56.6	53.8	54.3	53.7	53.2	53.5

	2019-20	54.3	50.4	52.4	53.8	54.8	55	54.2
	2020-21	55.5	58.1	54.1	53.4	53.9	54.3	53.5
	2021-22	51.47	56.73	52.87	53.17	52.43	52.95	52.23
	2022-23	55.6	58.1	53.7	53.7	54.0	54.3	53.2
Galaxy 2013	2017-18	55.9	58.9	53.5	54.3	52.9	54.2	52.6
	2018-19	54	59.2	53.2	54.9	54.3	54.3	54.2
	2019-20	54.3	52.5	53.8	54.8	55.1	56.2	55
	2020-21	56.5	59.8	54	54.2	55	55.8	55
	2021-22	54.27	59.13	53	54.5	54.2	53.83	53.1
	2022-23	56.0	58.2	54.3	54.2	55.3	54.8	55.5

Table 4: Test weight (g) of Wheat varieties on different dates of sowing 2017-2023

Test weight		D1	D2	D3	D4	D5	D6	D7
Faisalabad 08	2017-18	77.8	79.9	75	72.6	73.6	73.8	73.8
	2018-19	77.1	79.3	77.5	75.8	74.3	72.5	72.5
	2019-20	73.1	78.3	71.8	74	75	74.5	73.5
	2020-21	64.6	76.1	75.7	72.8	77.3	72.7	70.3
	2021-22	76.13	78.67	75.03	76.87	79.4	78.2	72.4
	2022-23	75.4	79.6	72.0	74.7	73.5	68.9	62.9
Punjab-11	2017-18	77.2	79.1	73.5	72.1	73.8	74.1	75.7
	2018-19	75.3	78	74.1	72.4	70.8	69.7	69.6
	2019-20	73.8	78.3	74.3	73.7	76.5	77	75.4
	2020-21	78.6	79.3	76.7	75.6	78.6	75.9	71
	2021-22	77.7	79.53	76.67	78.67	80.83	79.7	76.27
	2022-23	76.5	79.3	74.2	72.8	73.9	74.1	71.7
Galaxy 2013	2017-18	76.5	79.7	71.2	72.8	72.5	74	74.3
	2018-19	76	78.2	74	72.6	71.5	69.7	69.4
	2019-20	70.7	7.6	74	72.3	72.6	73	71.4
	2020-21	78	80.9	74	74.1	71.8	72.5	70.5
	2021-22	74.67	78.57	62.6	76.07	77.4	72.5	71.43
	2022-23	73.8	77.3	71.3	69.5	69.2	65.7	65.3

Table 5: 1000 grain-weight (g) of Wheat varieties in different dates of sowing 2017-2023

Grain weight		D1	D2	D3	D4	D5	D6	D7
Faisalabad-08	2017-18	22.3	39.8	37.4	32.3	33.6	35	29.1
	2018-19	34.71	38.07	35	36.7	33.83	30.2	30.37
	2019-20	32.2	38.23	33.3	29.43	31.17	32.4	30.2
	2020-21	39.8	37.4	39	37.7	37.2	30.9	25.8
	2021-22	35.93	37.47	30.93	31.83	33.47	33.35	26.45
	2022-23	41.60	43.27	29.10	28.47	31.00	25.53	23.67
Punjab-11	2017-18	40.4	42.5	35.2	31.2	33.2	28.9	31.4
	2018-19	33.49	40.87	20.1	34.33	30.77	29.7	29.23
	2019-20	30.2	37.93	28.87	29.8	31.35	34.63	31.53
	2020-21	42	44.4	43.1	41.1	38.8	34.3	27.3
	2021-22	36.27	43.4	32.4	35.67	41.37	39.15	29.67
	2022-23	38.13	41.73	33.20	31.60	32.30	30.67	29.33
Galaxy-13	2017-18	40.4	42.5		31.2	33.2	28.9	31.4
	2018-19	35.83	38.77	35.1	35.43	33.57	32.67	31.1
	2019-20	30.4	38.87	30.65	31.77	32.3	33.1	29.1
	2020-21	45.2	46.9	42.8	43.3	38.4	33.7	28.2
	2021-22	35.27	43.8	38.6	34.97	34.2	29.8	25.7
	2022-23	40.20	46.07	34.03	31.00	29.27	23.93	25.60

Table 6: Agrometeorological data of wheat season of six years 2017-2023

Year	Month	Temperature (°C) Mean		Rainfall Mean (mm)	Fog Number	Frosty Nights (Number)
		Max	Min			
2017-18	Oct	33.6	18.1	T	-	-
	Nov	29.2	13.6	T	6	-
	Dec	23.1	4.8	-	2	19
	Jan	19.5	4.1	3.2	1	16
	Feb		5.6	6.3	-	11
	Mar	28.1	12.9	1.8	-	-
	Apr	33.4	19.8	35.4	-	-
	May	39.7	24.3	0.1	-	-
2018-19	Oct	31.8	16.9	21	-	-
	Nov	27.3	11.3	-	5	-
	Dec	20.6	6.6	16.4	10	2
	Jan	18.7	4.4	3.2	7	10
	Feb	21	9.1	54.3	6	-
	Mar	28.8	13.6	1.9	-	-
	Apr	34.6	19.7	19	-	-
	May	40.8	23.7	1.3	-	-
2019-20	Oct	34.2	21.2	-	-	-
	Nov	27.7	10.6	1.6	-	-
	Dec	21.9	7.2	-	11	8
	Jan	20.7	5	-	11	9
	Feb	21.3	7.8	11.2	8	1
	Mar	26.5	13.1	30.6	-	-
	Apr	33.6	18.5	22.5	-	-
	May	37.5	23.7	63.5	-	-
2020-21	Oct	32.2	18.9	3.6	-	-
	Nov	27.5	10.6	22	-	
	Dec	19.3	5.4	-	17	4
	Jan	17.1	6.2	12.4	17	1
	Feb	23.1	10	23.3	3	-
	Mar	25.4	12.9	58.7	1	-
	Apr	34.3	20.6	22.5	-	-
	May	40.4	24.7	63.5	-	-
2021-22	Oct	32.9	19.6	13.6	-	-
	Nov	27.1	11.9	-	-	-
	Dec	22.7	6.4	-	6	8
	Jan	17.9	7	12.2	14	-
	Feb	24.6	7.9	5.8	3	-
	Mar	27.8	15.3	78	1	-
	Apr	35.4	20.5	6.1	-	-
	May	40.9	25.2	41	-	-
2022-23	Oct	34.7	19.6	25	2	-
	Nov	28.7	11.9	-	9	-
	Dec	24.7	8.2	-	8	1
	Jan	18.4	6.8	11.9	7	5
	Feb	24.8	8.6	3.7	-	-
	Mar	28.8	13.8	16.1	-	-
	Apr	37.5	20.7	19.2	-	-
	May	40	24.6	5.4	-	-

Results indicated that the test weight of Galaxy 13 was highest 89.1g in 2020-21 on the second date of sowing among all other varieties followed by Faisalabad 08 79.9g in 2017-18 table 4. The 1000 grain weight was found to be highest in Galaxy 13, 46.9g during 2020-21 on the second date of sowing table 5 followed by Punjab 11 manifested 44.4g during 2020-21. Tomas et al. (2020) observed a general decline in grain weight across various cultivars when subjected to heat stress, except for two varieties. Djanaguiraman et al. (2020) discovered that a sustained high temperature (32/22 °C over 14 days) during the grain filling phase led to a substantial 39% reduction in individual grain weight, although the impact of heat stress at the anthesis stage was minimal. Aiqing et al. (2018) noted a more pronounced decrease in spike grain weight for late-flowering tillers compared to early-flowering ones under heat stress conditions (34/16 °C, day/night

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temperature), attributing this to the late-flowering tillers undergoing heat stress during gametogenesis, while the early-flowering tillers faced it during the flowering period. Singh et al. (2020) reported a significant drop in grain weight for all wheat varieties under heat stress, with the extent of reduction correlating with the temperature rise. Ultimately, it was concluded that heat stress during the grain-filling stage resulted in the most considerable decrease in wheat grain quality parameters. Rising carbon dioxide levels often lead to higher ambient temperatures (Branlard et al., 2003). This increase in CO2 and associated heat stress can have varying impacts on the quality of different grains. Research by Fitzgerald et al. (2016) found that in semi-arid environments, the average size of kernels in varieties grew by 10-12% when exposed to elevated CO2 levels (550 μmol−1), compared to normal CO2 levels (370 μmol−1), indicating that higher CO2 levels could mitigate the negative effects of heat waves. In the case of winter wheat, the weight of 1000 kernels was observed to rise by 8-9% under combined conditions of elevated CO2 (600 μmol−1) and a temperature increase of 2.5-3.0 °C. Conversely, another study noted a decrease in thousand-kernel weight by up to 11.1% under elevated CO2 (550 μmol−1) and post-anthesis heat stress (32 °C), in contrast to standard conditions (21.7 °C and 380 μmol−1 CO2). Additionally, Zhang et al., (2016) reported an increase in globulin and albumin proteins, a decrease in gliadin and glutenin proteins, and a 1.60% rise in grain protein content under these stress conditions, without significant changes to amino acid content, except for aspartic acid, or to the distribution of glutenin macropolymers' particle size. Stress conditions altered the balance between gliadin and glutenin proteins in grains, with a notable decrease in the gliadin to glutenin ratio (1.29) and an increase in the ratio of high molecular weight to low molecular weight glutenin subunits (0.47) (Battenfield et al., 2016). Li et al., (2013) reported that the dynamics of carbon and nitrogen in grain amino acids were influenced by elevated carbon dioxide levels (700 μmol−1) and a rise in soil temperature by 2.4 °C. This environmental change led to varying impacts on amino acids, with some experiencing a decrease in their average percentage, such as alanine (from −8.16% to −5.7%), glycine (from −4.88% to −2.41%), and valine (from −6.58% to −5.09%), while others like tyrosine saw an increase (from +15.79% to +18.33%). The study concluded that the combined effect of increased carbon dioxide and higher temperatures resulted in a heavier kernel, along with higher levels of globulin and albumin proteins, and overall protein content in grains (Alhabbar et al., 2018a). Conversely, the levels of gliadin and glutenin proteins were found to be lower under these stress conditions. This research highlights the complex interactions between environmental factors and their impact on crop quality and nutritional value

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Declaration

Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

The study was approved by authors.

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Conflict of Interest

There is no conflict of interest among the authors regarding this case study.

Authors Contribution

All authors contributed equally.

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