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Investigation of generative high temperature tolerances of some cotton (*Gossypium hirsutum* L.) varieties

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Abstract

The potential of cotton genotypes to form buds, flowers and bolls is not sufficient to achieve cotton seed yield targets. Despite global warming buds, flowers and bolls that mature in cotton plants must be successfully transformed into products. However, this is related to the generative tolerance of the genotype to high temperature. In study aims to scan the negative effects of high temperature stress on the generative development on cotton varieties registered in Turkey in the last 10 years. The experiment was established in the GAP International Agricultural Research and Training Center trial field in 2020, with 4 blocks according to the Augmented design. Six standards (Tamcot Spnhix, SJU86, AGC208, ST468, ST474, Carmen) and 88 cotton varieties registered in Turkey National Variety List were used as trial material. In this study, high temperature pollen vitality stress index (HTPVSI) and high temperature shedding stress index (HTSSI) properties were investigated. According to the results of the experiments we conducted, it was determined that the HTPVSI values ranged between 0.17-1.26, the HTPVSI averages of the standards were 1.17, and the HTPVSI averages of the genotypes were 0.99. It has been determined that HTSSI values vary between 0.30-1.71. It was determined that the mean HTSSI values of the standards were 0.89 and the genotypes were 1.00. It was determined that there was a wide variation among the genotypes screened for generatively high temperature stress. Using HTSSI and HTPVSI features is recommended as a selection criterion since it is an important trait for screening genotypes in terms of tolerance or sensitivity to generative high temperature stress in cotton plants. In our study, the results were not similar to each other in terms of HTPVSI and HTSSI traits, due to the low share of flower shedding after applying HTSP (High Temperature Shock Practice: 96 hours of uninterrupted exposure to high temperature during generative periods) in the shedding rate. When the examined HTSSI and HTPVSI traits were examined together, no cotton genotypes were found to be generatively tolerant. In terms of sensitivity of genotypes to high temperature, 18 cotton genotypes were found in the medium tolerant group and 25 cotton genotypes were found in the sensitive group.

Keywords: Cotton, Generatively High Temperature, Pollen Vitality, Shedding

INTRODUCTION

Cotton plays an important economic role in the global economy due to its widespread use in the textile industry and providing job opportunities in the countries where it is grown (Khan, 2013; Yaşar, 2023). Cotton (*Gossypium hirsutum* L.), an important species of the mallow family and cultivated in nearly a hundred countries with temperate and tropical climates, is one of the indispensable raw materials of the industrial industry. In the 2021 and 2022 cotton production seasons, the world's four largest cotton-producing countries are India (5.9 million tons), China (5.7 million tons), the USA (4 million tons), and Brazil 2.7 million tons, respectively. In Turkey, seed cotton production increased by 26.9% in 2021 and amounted to 2.25 million tons (Anonymous, 2022). Considering the average data of the last 10 years in Turkey, the cotton cultivation area is 462 thousand hectares, the amount of fiber produced is 835 thousand tons, and the fiber yield is 19.3 kg ha^{-1}. (TUIK, 2022). In Turkey, cotton is grown intensively, especially in the Southeastern Anatolia Region, Aegean Region, Adana, and Antalya regions with the determining effect of climate factors. Approximately 59.31% of the cotton produced in our country is produced in the Southeastern Anatolia Region (Aytaç et al., 2020). However, due to the fact that the climate conditions of the Southeastern Anatolia Region are dry and hot in summer, high temperature has a negative and significant effect on the vegetative and generative periods of cotton. Cotton is frequently exposed to many biotic and abiotic stresses during its growth stages (Li et al., 2019; Yaşar, 2022). According to the International Intergovernmental Panel on Climate Change report, air temperatures are expected to increase by 0.2 °C every 10 years, with global warming being the key factor of high temperature stress. And from 2020 to 2080, the world temperature is predicted to increase by 0.5–5.44 °C (IPCC, 2007; IPCC 2018). Temperature trends display that the global average temperature may increase by 1–4 °C by the end of the 21st century (Driedonks et al., 2016). Although the temperature requirement of the cotton plant varies according to the growth stage, in conditions where it does not fall below 15°C, leaf, bud, flower, and boll development takes place and it tends to grow continuously, and temperatures of 25–32°C are sufficient for optimum growth (Reddy et al., 1997; Burke and Wanjura, 2010; Yaşar et al., 2019). If the temperature rises above 36°C, a significant decrease in fruit set is observed (Luo, 2011; Nasim et al. 2016; Singh et al., 2007). The optimum temperature values for the first development stages of cotton (main stem elongation, leaf area development, and biomass production) are 30/22°C day/night. Heat stress can be defined as the emergence of morphological, physiological, and biochemical changes in the plant that exceed the thermal capacity of the plant above the desired optimum temperature in its life cycle. Accordingly, since registered commercial cultivars with little resistance to high temperature stress have a narrow genetic base with limited genetic gain, these cultivars may increase their susceptibility in a stressful environment (McCarty et al., 2008; Wang et al., 2017; Ma et al., 2018). While the cotton plant produces four times more fruit branches at 30/22°C than at 20/12 °C, it produces fewer monopodial branches (Reddy et al., 1992). Going on of the daily maximum temperature affects the germination of cotton plants in the vegetative period, root and tiller growth, sympodial and monopodial branches, internode distance, photosynthesis, respiration, and ATP formation. In the generative period, it affects biomass, boll number per plant, boll size and weight, cellulose accumulation and fiber yield, fiber quality, fiber length, strength and micronaire value (Wahid et al., 2007; Bibi et al., 2008; Pettigrew, 2008; ITC, 2011; Loka and Oosterhuis, 2016). The high daily maximum temperature negatively affects pollination and fertilization in cotton plants (Kakani et al., 2005); It causes early maturation by bud-flower shedding (Reddy et al., 1995). It has been emphasized that temperature values between 33 °C and 40 °C have increasingly serious effects on pollen vitality and germination (Barrow, 1983). With the effect of the predicted global warming, temperature increases in the generative period depending on the severity and duration of the temperature can cause significant yield losses by causing a decrease in fertilization and pollen vitality, a decrease in the number of bolls, boll weights and hundred seed weights. It is of great importance to determine the negative effects of high temperatures in terms of species and varieties. Many techniques are used to identify high temperature tolerant varieties. In terms of high temperature stress, pollen vitality test and boll shedding are two important features in the generative period. The main aim of this study is to determine the response and tolerance status of some domestic and foreign origin cotton (*Gossypium hirsutum* L.) genotypes in the GAP International Agricultural Research and Training Center inventory, especially originating and registered cotton varieties in Turkey, to high temperatures in the vegetative period. At the same time, determining the parents with special characteristics and including them in the breeding program (Demiray et al., 2019) is to facilitate the researchers in breeding studies and to minimize the environmental effects in selection.

MATERIALS AND METHODS

Material

In this study, 94 cotton (*Gossypium hirsutum* L.) genotypes registered in Turkey National Variety List of domestic and foreign origin, cotton varieties originating from especially Turkey and registered were used as plant material (Table 1).

Experimental Design

The trial field was established in the trial area of the GAP International Agricultural Research and Training Center, in the cotton growing season of 2020, with 4 blocks according to the Augmented Design. ST474, Tamcot Sphinx, SJU86, ST468, AGC208, and Carmen genotypes were included as standard in the experiment. In the experiment, each of the parcels consisting of two rows is 4.0 m long and 1.4 m wide. In the experimental area established under field conditions, the cotton plant was subjected to high temperature shock practice (HTSP) by being placed in a low tunnel for an uninterrupted 96 hours during the peak flowering period. With the

Table 1. Some information about cotton genotypes

Origin of Material	Names of Cotton Varieties
ABD (USA)	Tamcot Sphinx, SJU86, AGC208
BASF Turkish Chem. Inds. and Trade Ltd. Comp.	Fiona, Carla, ST498, ST468, Carmen
Bayer Turkish Chem. Inds. Ltd. Comp.	Claudia, Gloria, Candia, Flora
Birlik Seed. Inds. and Trade. Ltd. Comp.	Bir781, Bir949, Cosmos, Bir138
Caso Seed. Inds. and Trade Ltd. Comp.	Caso 9048
EMTZARI	Furkan
EMARI	TYA193, Ceykot340, TYA366, ADN701, MAY355, MAY455, MAY505, TMK122, TMN18, MAY344, Nihal, ADN413, ADN710, ADN712, ADN123, ADN811, Gelincik, Sarıgelin, Çukurova1518, Bossa159, Teksa415, Yıldırım63, Ayzek595, Gapkot732, Ceykot 92
GAP ARI	ZN 243
GAP IARTC	Kartanesi
Golden West Seed Trade Ltd. Comp.	Optasia, Esperia, Bomba, GW2345, Babylon, Famosa, Fantom, Penta (Golda), Primera
Livagro Agr. Seed. Ltd. Comp.	Zara
May-Agro Seed Inds. and Trade Incorp. Comp.	Gaia, ST474, MAY404
Monsanto Nutr. and Agr. Trade. Ltd. Comp.	DP332, ST478, DP396, DP499, SG125
Özaltın Agr. Bus. Inds. and Trade Incorp. Comp.	Lodos, Özaltın404, Özaltın112
Özbuğday Agr. Bus.and Seed Incorp. Comp.	Lider (Mig119), Diva (Teks)
CRI	SC2009, SC2079, Efe, Ergüven, Harem1, Harem2, ES1, ES2, Sezener76, Özbek105, İpek607, Gürelbey, Aydın110, Şahin2000
Progen Seed Incorp. Comp.	Kaira, Lima, Astoria, Edessa, BA440, Carisma, PG2018, BA525, Flash
Tiriyo Seed. Ltd. Comp.	Zena1010, Zena1040, Zena1018

EMTZARI (East Mediterranean Transitional Zone Agricultural Research Institute), EMARI (East Mediterranean Agricultural Research Institute), GAPARI (GAP Agricultural Research Institute), GAP IARTC (GAP International Agricultural Research and Training Center), CRI (Cotton Research Institute)

help of the thermometer placed in the low tunnel, during the hot hours of the day (13:00-16:00), when the temperature is above 50°C, the low tunnel was opened from the sides to reduce the temperature. Observations were taken before high temperature shock application were recorded as Control. Observations taken at the end of the high temperature shock application period were recorded as Stress. Control and Stress observations were taken separately from 3 of the same plants, which were previously coded and selected in each plot, and the average of the observations was taken.

Pollen Vitality

Flowers blooming on the same day from 3 plants selected randomly from each plot and coded were used as material. In order to determine the pollen vitality levels of pollen belonging to the cotton genotypes in the experiment, 2,3,5, Triphenyl Tetrazolium Chloride (TTC) dye solution was prepared as specified by Norton (1966). Two coverslips were prepared for each genotype and counting was performed with light microscopy in 3 regions on each coverslip. During the count, the pollen stained red was considered as live, the pollen stained pink as semi-live and the pollen not stained at all as non-living. The living, semi-living and non-living pollen counts of the genotypes were determined.

Shedding Ratio (Buds-Flowers-Bolls)

High temperature shock practice (HTSP) before (control) and after (stress) periods were taken separately. Two-row parcels were created for each genotype. Three plants were randomly marked in these parcels. Bud/flower/boll numbers of the marked plants were taken separately as control and stress. Calculated using Formula 1 after counting.

$$\text{Shedding Ratio }(\%) = \left[\frac{\text{HTSP Before }(B-F-B)\text{ Numbers} - \text{After}(B-F-B)\text{Numbers}}{\text{HTSP After }(B-F-B)\text{ Numbers}}\right] \text{x1} \quad (1)$$

HTSP: High temperature shock practice

B-F-B: Bud/Flower/Boll

Pollen vitality test and shedding rate data obtained after control and stress were analyzed according to Augmented Design. It was calculated over the corrected values obtained after the analysis (Roger, 1985). High temperature stress indices for both properties examined were calculated according to Formula 2 according to the method of Fischer and Maurer (1978) and evaluated by modifying it according to Ekinci et al., (2012).

$$\text{HTSSI and HTPVSI}: \frac{\frac{GN - GS}{GN}}{\frac{AN - AS}{AN}} \qquad (2)$$

HTSSI: High temperature shedding stress index, HTPVSI: High temperature pollen vitality stress index

GS: Value of genotype under stress conditions, GN: Value of genotype under normal conditions

AS: Average of all genotypes under stress conditions, AN: Average of all genotypes under normal conditions

Regarding the evaluation of genotypes after calculating HTSSI & HTPVSI values; If HTSSI & HTPVSI ≤ 0.5 it was evaluated as "Tolerant", If 0.5< HTSSI & HTPVSI ≤1 as "Medium Tolerant" and If HTSSI & HTPVSI >1 as "Sensitive" (Khanna-Chopra and Viswanathan, 1999).

RESULTS AND DISCUSSION

Pollen Vitality

When controlled conditions were examined, pollen vitality percentages varied between 73.01 and 98.86%; While the average pollen vitality of the standards was 91.57%, the average vitality percentage of the genotypes was 89.88%. After high temperature shock practice (HTSP), pollen vitality rates of the experiment varied between 1.10-78.55%; While the average pollen vitality of the standards was 7.61%, the average of the genotypes was 19.43%. The histogram of the high temperature pollen vitality stress index (HTPVSI) feature is given in Figure 1a. High temperature pollen vitality stress index (HTPVSI) values varied between 0.17-1.26, the HTPVSI mean of the standards was 1.17, and the HTPVSI of the genotypes was 0.99. As a result of the evaluation made in terms of HTPVSI feature, it was determined that there are 54 Sensitive, 36 Medium Tolerant and 4 (ADN701, Optasia, Lima and Diva (Tex)) Tolerant cotton genotypes (Table 2, Figure 1). After high temperature shock practice (HTSP), it was determined that all cotton genotypes experienced stress in pollen vitality and as a result, their vitality values decreased. The findings we obtained, indicate that high temperature reduces pollen vitality. The findings of Song et al. (2015) and Alas (2022) show parallelism. Our findings show that flowers exposed to high temperature stress weaken and kill pollen vitality, or that semi-alive pollen weakens germination functions or causes loss of fertilization ability and stigma functions; It is similar to the findings of Barrow, (1983); Sato et al. (2002); Foolad, (2005); Firon et al. (2006); Maheswari et al. (2012); Ekinci et al. (2012); Dhatt and Kaur (2017) and Aladizgeh (2021).

Shedding (Bud-Flower-Boll)

When the bud, flower and boll (B-F-B) numbers were examined under controlled conditions, it was found that they varied between 11.84 and 20.51 per/plant; it was determined that the average number of B-F-B of the standards was 15.37 per/plant, and the genotypes were 15.99 per/plant. B-F-B numbers after high temperature shock practice (HTSP) varied between 7.72 - 17.17 per/plant; the average number of B-F-B of the standards 11.80 per/plant; genotypes were determined as 11.86 per/plant. In this context, it was determined that the shedding rates ranged from 8.50% to 79.34%, standards shedding rates were 30.41%, and the genotypes were 36.32%. The histogram of the high temperature shedding stress index (HTSSI) feature is given in Figure 1b. In the evaluation made within the scope of high temperature shedding index values, HTSSI values varied between 0.30 - 1.71; HTSSI values of the standards were found to be 0.89 and genotypes to be 1.00. In this context, it has been determined that there is a wide variation among genotypes. As a result of the evaluation made in terms of HTSSI feature, it was determined that 40 cotton genotypes were Sensitive, 51 cotton genotypes were Medium Tolerant and 3 cotton genotypes (Nihal, Lodos, Bir781) were Tolerant (Table 2, Figure 1). Our study states that there are yield losses as a result of small or dry boll formation as well as boll shedding due to the effect of high temperature in the cotton plant; by Yfoulis and Fasoulas (1978); Wullschleger and Oosterhuis (1990); Rawson (1992); Reddy et al. (1999); Zhao et al. (2005); Hatfield et al. (2008, 2011); Oosterhuis (2009) and Karademir et al. (2012) are similar to their research.

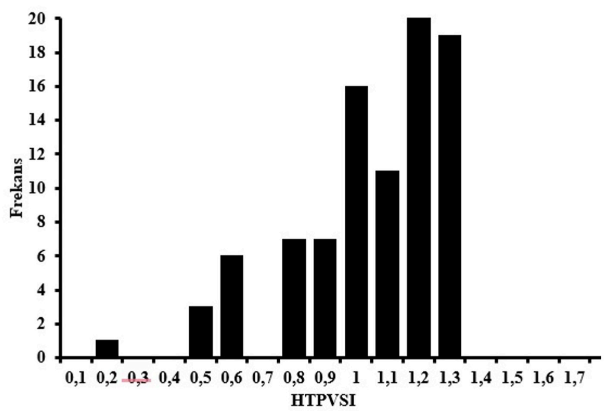

Figure 1a. Histogram for the HTPVSI feature

The variation of genotypes HTPVSI and HTSSI is given in Figure 2.

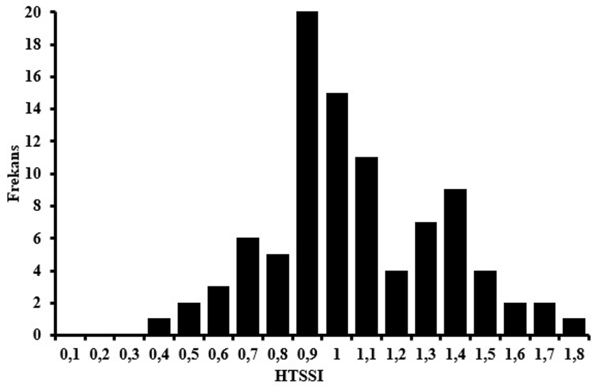

Figure 1b. Histogram for the HTSSI feature

In Figure 2, it is understood that as the genotypes get closer to the origin, there is more generatively tolerance in terms of both traits. In terms of HTPVSI and HTSSI characteristics examined, the Tolerance Zone (HTPVSI ≤0.5 and HTSSI≤ 0.5) was marked as TZ. Sensitivity Zone (HTPVSI >1.00 or HTSSI>1.0) was marked SZ. The Medium Tolerance Zone (0.5< HTPVSI ≤ 1.0 or 0.5<HTSSI≤1) was marked as MTZ. However, the Medium Tolerance Zone consists of three parts: MTZ, Gray I and Gray II. Although the Gray I region is tolerant in terms of the HTSSI feature, it is seen to be in the Medium Tolerant group in terms of the HTPVSI feature. Similarly, although the Gray II region is tolerant in terms of the HTPVSI feature, it is noticed that it is in the Medium Tolerant group in terms of the HTSSI feature. Therefore, Gray I and Gray II zones

Table 2. Genotype Numbers of Sensitive, Medium Tolerant and Tolerant groups according to HTSSI and HTPVSI

Groups	In terms of HTSSI	In terms of HTPVSI	In Terms of Both Traits
Sensitive	**40**	**54**	**25** Astoria, MAY455, Efe, Ergüven, Harem1, Sezener76, Babylon, Carisma, PG2018, Furkan, Kartanesi, Claudia, Gloria, ST478, Çukurova1518, BA525, Gürelbey, Aydın110, Bossa159, Ayzek595, Gapkot732, Caso9048, Flora, Flash, SJU86
Medium Tolerant	**51**	**36**	**18** (Ceykot340, TYA366, Bomba, MAY355, TMK122, Özaltın404, Özaltın112, ADN413, BA440, Sarıgelin, Famosa, Fantom, Penta (Golda), Candia, Şahin2000, Teksa415, Yıldırım63, Gaia)
Tolerant	**3** (Nihal, Lodos, Bir781)	**4** (Optasia, ADN701, Lima, Diva (Teks))	**0**

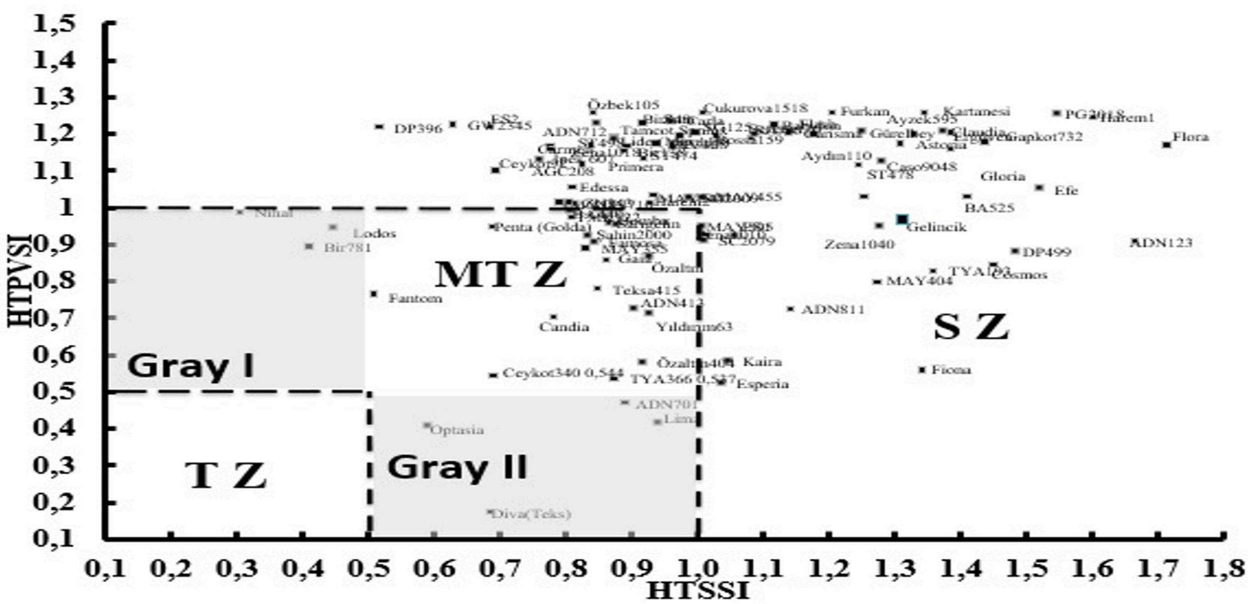

Figure 2. HTPVSI and HTSSI Change Graph of Genotypes

were included in the Medium Tolerant Zone (Figure 2). In terms of both traits, 25 cotton genotypes (Astoria, MAY455, Efe, Ergüven, Harem1, Sezener76, Babylon, Carisma, PG2018, Furkan, Kartanesi, Claudia, Gloria, ST478, Çukurova1518, BA525, Gürelbey, Aydın110, Bossa159, Ayzek595, Gapkot732, Caso9048, Flora, Flash and SJU86) were located in the Sensitive region (SZ) while 18 cotton genotypes (Ceykot340, TYA366, Bomba, MAY355, TMK122, Özaltın404, Özaltın112, ADN413, BA440, Sarıgelin, Famosa, Fantom, Penta (Golda), Candia, Şahin2000, Teksa415, Yıldırım63 and Gaia) were located in the Medium Tolerant region (MTZ). In terms of both traits, the cotton genotype in the Tolerant group could not be determined (Table 2). Gray I and Gray II regions can be considered as more advantageous regions than MTZ regions. Although flower shedding, which is included in the shedding ratio, is directly related to pollen vitality, boll and bud shedding is not related to pollen vitality. The results do not show similarity with each other in terms of HTPVSI and HTSSSI properties because the share of flower shedding in the shedding ratio (B-F-B) is low. Shedding of buds, which are sensitive to the effect of high temperature stress in cotton cultivation, may result in the shedding of bolls under more severe stress conditions. As a result, serious yield losses will be inevitable.

CONCLUSION

It was concluded that boll and bud shedding occurred much more than flower shedding since HTSP (96 hours of uninterrupted exposure to high temperatures during generative periods) in our study created very severe heat stress for genotypes. Therefore, severe and prolonged high temperatures have become inevitable to cause serious yield losses. It is recommended for the screening of genotypes in terms of tolerance or susceptibility to generatively high temperature stress in cotton plants by using HTPVSI and HTSSI features. In addition, it is suggested that it would be beneficial to use HTPVSI and HTSSI traits in selection in breeding programs. Prolonged and severe high temperatures will inevitably cause yield losses. HTPVSI and HTSSI characteristics were examined together, and no genotype was included in the generatively tolerant group. In terms of sensitivity of genotypes to high temperature, 18 cotton genotypes were found in the medium tolerant group and 25 cotton genotypes were found in the sensitive group.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest

The authors declared that for this research article, they have no actual, potential or perceived conflict of interest.

Author contribution

This article was produced from the Y.G.D. PhD thesis, and the supervisor of the thesis is R.E. and the co-supervisor is A.B. All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Ethics committee approval is not required.

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Data availability

Not applicable.

Consent for publication

Not applicable.

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