Physiological functioning of *Lagerstroemia speciosa* L. under heavy roadside traffic: an approach to screen potential species for abatement of urban air pollution

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Received: 7 February 2017 / Accepted: 10 March 2017 / Published online: 25 April 2017
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Abstract The mitigation potential of avenue tree species needs a sound understanding, especially for landscape planning or planting tree species on roadside, especially in city limits where there is huge traffic due to more number of vehicles. A preliminary study was conducted to investigate the impact of heavy traffic movement and pollution thereof on physiological functioning of *Lagerstroemia speciosa* trees planted on roadside in terms of carbon absorption, mitigation potential and adaptive behavior. Trees on roadside exhibited reduced carbon assimilation ($36.7 \pm 2.4\%$) and transpiration rate ($42.14 \pm 2.9\%$), decreased stomatal conductance ($66.85 \pm 3.87\%$), increased stomatal resistance ($212.2 \pm 11.25\%$), more leaf thickness (40.54 ± 3.25) and water use efficiency ($9.4 \pm 0.87\%$), and changes in lead ($179.31 \pm 10.24\%$) and proline ($15.61 \pm 1.92\%$) concentration in leaf tissues when compared to less traffic area (FRI campus). The impacts were also witnessed in the form of enhanced vapour pressure deficit of air ($63.18 \pm 4.94\%$) and leaf ($45.72 \pm 3.25\%$), and air temperature ($3.2 \pm 0.16\%$) and leaf temperature ($9.0 \pm 0.82\%$) along roadside trees. It was

inferred that heavy traffic movements interrupt the physiological functioning of trees due to alteration in the surrounding environment as compared to non-traffic areas. The present study provides baseline information to further explore and identify the potential avenue tree species having significant mitigation potential and adaptive efficiency to heavy traffic movements for improving urban environment.

Keywords *Lagerstroemia speciosa* · Carbon assimilation · Stomatal conductance and resistance · Urban pollution · Adaptation and mitigation · Roadside plant physiology

Introduction

India is one of the fastest growing economies of the world. With increasing economy and improved lifestyle, the numbers of vehicles are also increasing at much faster pace. This has influenced the urban environment and its vegetation. Urban vegetation plays a significant role in ameliorating environment of the cities. In light of giving extensive environment services through urban plantation or increasing green urban cover, most of the developing countries are enthusiastic to incorporate urban vegetation in their development plans (Janhall 2015; Andersson-Skold et al. 2015). The urban pollution is a serious problem in both developing as well as developed countries (Li 2003). The frequency and movement of vehicles alter the urban environment causing air and soil pollution, which is a major alarming issue now a days worldwide. Besides plant health, air pollution in the urban areas also affects human wealth and health (Rai 2013). The urban pollution affects carbon absorption potential of urban vegetation and alters other functional traits. Many of these traits are related to

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the mitigation and adaptation potential, which are mostly affected by the air pollutants such as carbon monoxide, lead, oxides of nitrogen (NO_x), volatile organic compounds (VOCs), sulfur dioxide (SO₂), carbon dioxide (CO₂), fine particles and other toxic chemicals. These pollutants affect the plant growth and physiological behavior of vegetation in urban area (Durrani et al. 2004; Chauhan 2010; Narwaria and Kush 2012; Wittenberghe et al. 2013).

Additionally, the urban conditions near roadsides also have impacts on photosynthetic pigments, activities related to respiration, enzymatic activities at metabolic level, gas exchange and stomatal physiology, etc. Besides these effects, increasing pollutants in urban area are also expected to have major impacts on the biological clock of plants and consequently affecting the phenological (flowering, fruiting, etc.), physiological (leaf development, leaf thickness, senescence, etc.) and biochemical (accumulation of osmolite, etc.) characteristic of plants. Ultimately, all these phenomena adversely affect the carbon uptake, mitigation and adaptation potential of vegetation (Prajapati and Tripathi 2008; Liu and Ding 2008; Honour et al. 2009; Narwaria and Kush 2012; Leghari et al. 2013; Parveen et al. 2014).

However, the studies done so far related to impact of vehicular movement on urban environments are confined to quality of air and soil systems. Lack of sufficient literature regarding mitigation and adaptive characterization at physiological level makes it important to understand how tree species respond to changing conditions prevalent in urban areas in the era of global climate change. Thus, to understand plantation response to urban circumstances in terms of urban physiology, there lies a key opportunity to have an insight on quick physiological responses, tolerance of vegetation, and the degree and mechanisms of short and long term plant adaptations. The environmentalist or plant physiologist can use urban environment as an “Open Lab” wherever interventions in environment taking place with no cost and no restriction of the laboratory when compared to high cost technology such as open top chambers (OTCs), free air CO₂ enrichment (FACE), free air O₃ enrichment and free air humidity manipulation (FAHM) (Calfapietra et al. 2015; Singh 2015; Kupper et al. 2011). Calfapietra et al. (2015) stressed upon the utilization of urban vegetation as an open lab in urban environments which could be exploited much more by scientists who are willing to study how changing environmental variations would affect the vegetation in near future.

Considering the above facts, the present study was conducted to analyze the mitigation and adaptive behavior of young *Lagerstroemia speciosa* L. trees planted on the roadside of the National Highway (Dehradun to Himachal Pradesh and Chandigarh) in Dehradun City in Doon valley of Himalayan foothills. An attempt was also made to prove

the hypothesis as to whether environmental pollution caused by heavy traffic movement influences the carbon absorption and other process potentials.

Materials and methods

Site characteristics

Climatologically, the study area comes under the subtropical region which experiences the flavor of both temperate and tropical climate. The minimum air temperature ranges from 4.00 to 23.00 °C and maximum between 20.00 and 34.00 °C. The average air temperature of the last 20 years varied between 11.64 and 27.34 °C, lowest in January and highest during June, respectively. The relative humidity ranged between 52.11 and 85.16% during April to August, respectively. The 20-year rainfall data showed maximum rainfall during August (568.12 mm), while minimum in November (3.74 mm). Sunshine hours per day averaged for last 20 years showed highest in the month of May (9.34 h day⁻¹). The meteorological data were obtained from Forest Meteorological Observatory, Forest Research Institute, Dehradun.

Model tree and measurement of biological process

The study was conducted in two different conditions based on frequency of traffic movement (Fig. 1). All observations were made during the month of October 2016. The *Lagerstroemia speciosa* L. trees of even age (approx., 14 feet height) were selected along National Highway in Dehradun city (30°19′58.2″N and 77°00′06.3″E to 30°19′56.1″N and 77°58′59.4″E). The frequency of vehicular movement per hour was counted manually and on the average, about 812 vehicles pass per hour in both directions on this highway which constitute approx 389 (two wheelers), 138 (three wheelers), 262 (four wheelers) and 22 heavy vehicles. The planted area in the campus of Forest Research Institute (FRI) Dehradun (30°20′00.0″N and 77°59′37.3″E to 30°20′13.2″N and 77°59′36.5″E) was considered as control site having least movement of traffic. Inside FRI campus on selected road (Lauri road), around 20 vehicles per hour pass through the road (Fig. 1). Five trees in each experimental site were selected. The functioning traits associated with mitigation and adaptive behavior such as carbon assimilation rate (A — $\mu\text{mol m}^{-2} \text{s}^{-1}$), water releasing rate (E — $\text{mmol m}^{-2} \text{s}^{-1}$), stomatal conductance (g_s — $\text{mmol m}^{-2} \text{s}^{-1}$), vapour pressure deficit of leaf and air, leaf and air temperature and incoming solar radiation ($W \text{m}^{-2}$) were investigated with the help of a portable photosynthesis analyzer (LI-COR-6400 XT, Lincoln, NE) by taking healthy and young leaves between

Fig. 1 Experimental area, National Highway and FRI campus

09:30 am and 01:30 pm under clear sky conditions. During measurements, relative humidity was found to be around $50 \pm 4\%$, photosynthetically active radiation (PAR) was above $1290 \pm 20 \mu\text{mol m}^{-2} \text{s}^{-1}$ and CO_2 concentration near about $400 \pm 3 \mu\text{l l}^{-1}$. The water use efficiency (A/E — $\mu\text{mol CO}_2 \text{mol}^{-1} \text{H}_2\text{O}$) was computed with the ratio of carbon assimilation rate and water releasing rate (Singh, 2015). The leaf thickness was measured using a digital vernier caliper. All parameters were observed for the same leaf of the plant. For canopy level measurement, a ladder of 15 feet height was used. The canopy was divided into three strata, i.e. bottom, middle and top. Canopy spread over in all directions in each stratum was considered for measuring functioning traits. After measurement of traits, the leaves were detached from twig of the tree and brought to laboratory for estimation of proline and lead concentration (mg g^{-1}) following the methods of Bates et al. (1973) and Jackson (1965), respectively. The data were subjected to statistical analysis for observing error and understanding correlation between functional traits (Cochran and Cox

1957). The statistical software, namely, Genstat was used to analyse the data. The comparison of magnitude in terms of increased or decreased percentage of each trait under both conditions was carried out. The data were represented as the mean of the observation along with standard deviation.

Results

Analysis of mitigation and adaptation traits: CO_2 assimilation, water exchange, and stomatal conductance

The influence of altered environment due to the emission of pollutants from heavy traffic movement on functioning of trees is summarized in Fig. 2. The trees planted on the roadside of the national highway (Dehradun to Chandigarh and Himachal Pradesh) showed decreased trends in CO_2 assimilation rate ($36.7 \pm 2.4\%$) with the value of

Fig. 2 Mitigation and adaptation traits' response of *Lagerstroemia speciosa*

$6.31 \pm 0.53 \mu\text{mol m}^{-2} \text{s}^{-1}$ as compared to FRI campus ($9.97 \pm 0.85 \mu\text{mol m}^{-2} \text{s}^{-1}$) (Fig. 2a). Water loss through the process of transpiration from the leaf of tree was also found to be lowest for roadside plantation where vehicular movement was more. The rate of water loss was noted to be higher ($5.53 \pm 0.69 \text{ m mol m}^{-2} \text{s}^{-1}$) at FRI where traffic was less, and lower ($3.19 \pm 0.56 \text{ m mol m}^{-2} \text{s}^{-1}$) to the trees planted on the roadside of the national highway, which decreased around $42 \pm 2.9\%$ in the roadside plantation (Fig. 2c).

The water use efficiency as the ratio of CO₂ assimilated and water transpired was slightly increased in canopy of tree planted along the roadside of national highway and was not significant. The value of water use efficiency for roadside plantation was investigated as $1.99 \pm 0.20 \mu\text{mol CO}_2 \text{mol}^{-1} \text{H}_2\text{O}$, while $1.82 \pm 0.17 \mu\text{mol CO}_2 \text{mol}^{-1} \text{H}_2\text{O}$ to FRI campus plantation, which was $9.4 \pm 0.87\%$ greater than those of FRI campus (Fig. 2d). It was noted that heavy traffic movement induced declining opening and closing of stomata in terms of stomatal conductance when compared to the same activity in plants of FRI campus. The stomatal conductance of plantation at uninterrupted area was greater

($66.85 \pm 3.87\%$) than traffic area with the observation of 0.38 ± 0.08 and $0.13 \pm 0.03 \text{ mmol m}^{-2} \text{s}^{-1}$, respectively (Fig. 2b).

Analysis of vapour pressure deficit and temperature of air and leaf tissue

Understanding the physiology of plants growing in both environments, the vapour pressure deficit (VPD) of air and leaf was also measured which showed variations and, hence, was considered as a good indicator of environmental stress on plant systems.

The VPD is summarized in Fig. 3. The analysis of VPD in respect of leaf and air for plant growing inside FRI campus did not show significant difference but was significant when compared to plantations along roadside of National highway. The VPD of air and leaf at FRI campus and roadside plantation ranged between 1.50–1.53 kPa and 2.18–2.45 kPa, respectively (Fig. 3b). Besides VPD, heavy traffic movement also affects air and leaf temperature of plantation which is probably because of vehicular movement. The impact of vehicular movement on temperature is

Fig. 3 Temperature and vapour pressure deficit of leaf and air at roadside and FRI campus conditions

illustrated in Fig. 3a. An increase in air and leaf temperature was recorded for plants growing along roadside when compared to control site. The air temperature at roadside was found to be 32.95 ± 0.19 °C, whereas it was 31.89 ± 0.12 °C at control area. During study period, leaf temperature at roadside plantation also confirmed increased pattern with the value of 34.97 ± 0.24 °C and lower at control site (32.10 ± 0.22 °C).

Analysis of biophysical traits: leaf thickness and stomatal resistance

The biophysical traits of plantation for both areas which are directly linked to the potential of mitigation and adaptation under altered conditions are presented in Fig. 4.

It was observed that leaf thickness of plantation at roadside was less (0.44 ± 0.012 mm) than that found in controlled conditions (0.74 ± 0.016 mm). The significant influence of heavy traffic movement on the magnitude of thickness in the form of increased thickness was maximum ($40.54 \pm 3.25\%$) when compared to FRI campus (Fig. 4a). During the study period, it was found that stomatal resistance of trees on roadside is severely affected by heavy traffic movement. The stomatal resistance of trees had decreased around $212.2 \pm 11.25\%$

when compared to FRI campus where it was 27.68 ± 1.32 and 86.44 ± 2.87 s m⁻¹, respectively (Fig. 4c).

Analysis of biochemical indicator of adaptation: lead and proline accumulation in leaf tissue

The biochemical traits of leaf tissues also exhibited huge variations at both experimental areas. The fluctuations in accumulation of biochemical traits, lead (a heavy metal) and proline (a stress indicator) are represented in Fig. 4. The lead accumulation in leaf tissues of roadside trees was much impacted and when analyzed (0.87 ± 0.06) was $179.31 \pm 10.24\%$ more rather than that in FRI campus (2.43 ± 0.11). The lead concentration in leaf tissue is presented in Fig. 4d which was found to differ significantly for both the sites. Similarly, proline concentration in leaf tissue showed increased trend and was maximum (0.089 ± 0.003 mg g⁻¹) for roadside plants when compared to plants of FRI campus (0.077 ± 0.002 mg g⁻¹). The proline content in leaf tissue was $15.61 \pm 1.92\%$ which was more than controlled conditions of FRI campus (Fig. 4b).

Relationship between functional traits

The relationship between functional traits is illustrated in Figs. 5 and 6. It was interesting to analyze that most of the parameters demonstrated a significant relationship. The decreased CO₂ assimilation rate and increased leaf thickness for plantation of roadside and those in FRI campus showed linear relationship ($R^2 = 0.94$). Apart from CO₂ assimilation and leaf thickness, a linear relationship was also found between transpiration and CO₂ assimilation rate ($R^2 = 96$), CO₂ assimilation rate and stomatal resistance ($R^2 = 79$) and transpiration and stomatal resistance ($R^2 = 73$). Besides, stomatal conductance also showed a good relationship between CO₂ assimilation rate and stomatal resistance ($R^2 = 77$ and $R^2 = 99$, respectively). Proline and lead concentration in urban trees had showed direct relationship with the pollution loads of the environment.

Discussion

Response of CO₂ assimilation, water exchange and stomatal conductance

Lagerstroemia speciosa trees exposed to roadside environment demonstrated reduction in CO₂ assimilation rate, transpiration rate and stomatal conductance (Fig. 2). This might be due to deposition of dust particle and particulate matter on leaves of the trees which reduce stomatal

Fig. 4 Impact of roadside and control environment on leaf biophysical and biochemical indicators of *Lagerstroemia speciosa*

opening inducing reduced stomatal conductance. The reduced stomatal conductance because of interrupted gas exchange declines rate of CO₂ assimilation and water exchange. This decreases the process of photosynthesis and transpiration. The reduced water transpiration from the leaves affects the physiological water use efficiency of the plant system. These results provide a fascinating paradigm of the responses of leaves to environmental discrepancy, showing that leaf capacity to regulate photosynthesis and transpiration results in huge changes in water use efficiency which is quite similar to the findings of Medrano et al. (2015). The CO₂ assimilation rate, stomatal conductance and transpiration rate are key functional parameters of any vegetation to enlighten upon various environmental services which are linked to these physiological traits of plants. Undoubtedly, every impact of urban environment, particularly roadside environment on these traits might have strong impact on the ability of the plants to mitigate environmental changes in climate change scenario (Calfapietra et al. 2015). It has been reported that canopy of the urban trees along the roadside

acts as a sink for huge number of vehicular air pollutants. The alteration at the level of physiological, morphological and biochemical levels leads to induces structural and functional changes resulting in decline of CO₂ assimilation rate, stomatal conductance and water loss through the process of transpiration as presented in Fig. 2 which has also been reported by Rai and Panda (2015). Present study indicates that the air pollutants can disturb stomatal functioning ultimately affecting the overall physiological behavior of plant. It has also been reported that roadside or urban environment affect stomatal movement, leaf temperature in turn of acting photosynthesis and transpiration processes (Panda and Rai 2015; Rai et al. 2010; Naidoo and Chirkoot 2004). Bojarczuk et al. (2002) reported reduced carbon assimilation rate of (*Betula pendula*) plants under polluted environment which was found to be lower by 31% than plant growing unpolluted conditions. The rate and total amount of air pollutant in urban area affect photosynthesis, water use efficiency, respiration, leaf conductance and leaf longevity. The reduction in rate of these traits badly influences canopy

Fig. 5 Relationship between functional traits of *Lagerstroemia speciosa*

Fig. 6 Relationship between functional traits stomatal conductance, CO_2 assimilation rate and stomatal resistance of *Lagerstroemia speciosa*

carbon fixation and net assimilation of carbon dioxide and also decreases transpiration which leads to slight increase in water use efficiency. The similar results were reported on physiological response of plants towards heavy pollution stress by various workers (Dong et al. 2007; Cui et al. 2006; Singh et al. 2008; Tripathi et al. 2011; Chaturvedi et al. 2013).

Behavior of vapour pressure deficit (VPD) and temperature of air and leaf tissue

The VPD and temperature of leaf and ambient air were found higher at roadside which was also reported in previous findings (Farmer 1993; Eller 1977; Hope et al. 1991; Keller and Lamprecht 1995; Fluckinger et al. 1979;

Stanghellini and van Meurs 1992). The dust on canopy of roadside trees decrease resistance which boost temperature of the leaf; this wonder makes plants more vulnerable to dry environment brought about because of expanded temperature (Farmer 1993). The optical nature of leaves, mainly leaf surface reflectance in the visible and shortwave infrared radiation is reduced due to surface dust deposits resulting in increased leaf temperature (Eller 1977, Hope et al. 1991; Keller and Lamprecht 1995). The dust in urban environment causes reduction in stomatal diffusive resistance that gives a route to increased leaf temperature of *Populus tremula* (Fluckinger et al. 1979). The increased leaf and air temperature damages the surface and internal structure of leaves inducing decline in transpiration and photosynthesis rates ultimately resulting in reduced productivity of plants under polluted environment. The correlation between water transpired and atmospheric humidity is mainly associated to the stomatal response to the variation in leaves and air VPD. Air VPD is one of the important environmental factor regulating growth and development of the plants under changing environmental conditions. The warm air can seize maximum water vapour than cool air, so the vapour pressures of water in warm air can reach higher values than in cool air (Stanghellini and van Meurs 1992).

Response of biophysical traits: leaf thickness and stomatal resistance

In urban conditions, the uptake and absorption of air pollutants is commonly considered to be corresponding to the flow of electrical current through resistors placed in parallel or series arrangement. The resistance to transfer from the atmosphere to the sub-stomatal canopy is considered to be the sum of the atmospheric resistance, the boundary layer resistance and the stomatal resistance where latter is influenced by several factors viz. temperature, humidity, toxicity of pollutants, leaf hairs, leaf wax and leaf thickness. Out of these factors, leaf thickness is important factor controlling stomatal functioning under the influence of polluted environment which reflects the adaptive and mitigative character of plants for coping with severe environmental conditions. Kardel et al. (2009) studied stomatal and leaf characteristic of *Plantago lanceolata* under urban habitat and reported increased stomatal resistance in the urban and industrial land use class in comparison with the sub-urban green. The species-specific stomatal resistance is influenced by the effects of climatic conditions on the aperture of the stomatal pores. The leaf thickness or surface attracts the pollutants and get deposited on surface. The deposition of pollutants on leaf surface is mostly regulated

by the cuticular surface of the leaf, especially if it is wet by rain or dew. Leaf thickness with large surface area could act as a good indicator of adaptation and mitigation of plants under polluted area (Emberson et al. 2001). The increased leaf thickness under increased air temperature due to the heavy traffic movements during this study was also similar to results obtained by Moura and Alves (2014) for *Ipomoea nil*. It was reported by them that increased temperature of surrounding environments of tree *Ipomoea nil* 'Scarlet O'Hara' induced to enhance leaf thickness of the plant system. Therefore, it is myth that pollution adversely affects vegetation; however, its impact on phenology and leaf morphology is not satisfactorily understood fully yet and it has been reported that particularly ozone significantly associated with delaying in of phenology of urban vegetation systems (Jochner et al. 2015).

Response of biochemical indicators: Lead and proline in leaf tissue

The present study revealed increase in accumulation of biochemical substances such as lead (Pb) and proline in their leaves for the plant growing on roadside of National highway compared to control environment (FRI campus). The accumulation of these bio-chemicals in leaf tissues protects the plants from environmental stress. In view of the fact that plants are stationary and therefore continually exposed to environmental variation, the effect of air quality has a high impact on them (Agbaire 2016). Once the plants are exposed to air pollution and immediately, they try to develop adaptation mechanism in leaf tissues or root for as a survival mechanism that direct to the accumulation of some organic solutes such as sugars, polyols, betains and proline (Yancey et al. 1982). Studies have shown an increase in proline content of leaves under stress condition (Hare and Cress 1997; Mohammadkhani and Heidar 2008; Seyyednejad and Koochak 2011). Various reporters had reported about proline accumulation in response to environmental stress (Ozturk and Denir 2002; Kavi et al. 2005; Khedhar and Gadge 2014). It is believed that accumulation of proline is an adaptive phenomenon if proline accumulation happens in leaf tissue under polluted environmental conditions (Verbruggen and Hermans 2008). Jaleel et al. (2007) stated that accumulation of proline in leaf tissues under stressed environment is a good indicator to screen pollution stress tolerant species. The present study has been parallel to the above findings. Few metals including lead act as trace element that are essential for performing plant performance at metabolic level in very small amounts. When they are available in trace amount it work as inducer of metabolic process while its presence in excess has the potential to

become toxic to plant systems (Nagajyoti et al. 2016). Wagela et al. (2002) reported maximum accumulation of lead content in leaf tissue of *Dalbergia sissoo* grown at roadside in urban area of Indore city of India and findings was similar to this study. Lead accumulation in leaves of trees was also reported by Salazar and Pignata (2014) under polluted environment. The study carried out at worldwide and under this study showed that lead and proline accumulation in leaf tissues in plants of urban area can be used as indicator of tolerance and adaption for screening of plant species which can uptake and absorb the higher amount of heavy metals and could be planted under urban area where air pollution is supposed to be more in future due to traffic movements and other anthropogenic pressure.

Most of the functional traits demonstrated positive relationship (Figs. 5, 6). The CO₂ assimilation was found to be positively associated to the opening and closing of stomata (stomatal conductance) and transpiration rate. The increased pollution declines the gaseous exchange between plant and environment due to partial closure of stomata. This mechanism minimizes water loss and improves water use efficiency. The increased leaf thickness reduces CO₂ assimilation, transpiration and stomatal conductance in the plants planted on roadside. The relationship between traits of present study is similar to other studies conducted worldwide (Stanghellini and van Meurs 1992; Emberson et al. 2001; Salazar and Pignata 2014; Khedhar and Gadge 2014; Jochnner et al. 2015; Calfapietra et al. 2015).

Conclusion

The increased air pollution because of heavy traffic could alter the adaptation and mitigation behavior of tree species. The reduced capacity to assimilate carbon dioxide influences physiological, morphological and biochemical traits of the plant. The thickness of leaves affecting stomatal closing and opening lowers the stomatal conductance and hence reduces CO₂ assimilation. The deposition of dust on leaf surface leads to reduced leaf transpiration which in turn increases the internal leaf temperature. The plants alter its adaptation and mitigation properties under the influence of metabolic and morphological induced changes under the influence of polluted environment. Amplified accretion of biochemical like lead and proline and physiological traits can be used as indicator to assess tolerance of plants for air pollution. Further investigations can help in selecting species for areas where the ambient pollutant load is higher. This will provide a better alternative to combat pollution through plantation of selective species and using *Lagerstroemia speciosa* and/or other similar plant species for the green belt development.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest in the publication.

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