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Morphological Adaptations for Stress Tolerance in Chickpea (*Cicer arietinum* L.)

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ABSTRACT: Chickpea is a very important leguminous crop and is cultivated in many regions. It is a major source of protein and contains an ample amount of nutrients, amino acids, and carbohydrates as well, thus it is suitable for both humans as food and for animals as feed. It was observed that in 2020, the total production of chickpea around world is 15 million ton in which several countries are involved such as 73% India, Turkey, Myanmar and Pakistan termed as secondary producer. If we talk about total production and productivity in India alone, the area covered by chickpea in India is 8.12 M hectare with a production of 7.46 million ton, and productivity of 895kg/hectare in Madhya Pradesh rank first with a total production of 3.09 M ha, Maharashtra rank second with the production of 1.29 M ha and Karnataka rank third with the production of 0.97M ha. Being a leguminous crop, it has an inherent tendency to fix atmospheric nitrogen which increases the fertility of the soil. The main reason for the loss of quality and yield is various stress conditions viz. heat stress, salinity stress, chilling stress, drought stress, etc. This stress adversely affects the productivity of the crop. To cope with this stress the crop has undergone some morphological adaptations *i.e.*, morphological traits like the number of branches, root length, etc. help in adapting and tolerating the drought stress conditions. However, such changes occur at a very slow rate and are insufficient to overcome the yield loss. For this, breeding is used to develop stress-tolerant genotypes basically in form of early maturing genotypes. These morphological adaptations are helpful in guiding a breeder in developing climate resilient cultivars that could give better yield under various types of climatic rigours. This review paper provides the whole information about the chickpea crop, their adaptations, stress conditions in chickpea and stress tolerance mechanisms that would be helpful in guiding chickpea improvement programme.

Keywords: Adaptations, Breeding, Chickpea, Stress, Tolerance.

INTRODUCTION

Chickpea (*Cicer arientinum* L.) is the most important legume crop after the common bean and it is commonly grown in arid and semi-arid regions. It is a highly self-pollinated crop in the Fabaceae family with around 28000 genes dispersed on 16 chromosomes (Mart *et al.,* 2021). There are two types of chickpeas first one is small-seeded known as desi and the other is large-seeded known as Kabuli chana, there is a difference in both plants like the morphology of the coat differs from each other and the colour of the flower too (Devasirvatham *et al.,* 2018). Chickpea is used to feed both animals and humans as the nutritional value is high it contains carbohydrates, essential amino acids, types of sulphur, unsaturated fatty acid (linoleic and oleic acid), various vitamins such as riboflavin, niacin, thiamine, folate, magnesium, phosphorus and potassium. Chickpea also has medicinal values as it has the potential to reduce the diseases of humans like cardiovascular disease, diabetes specifically types II, any digestive problems, and cancer, not only it is beneficial for consumers but also where it is cultivated the land is also benefitted it is used for crop rotation and break the disease for cereal crops, along with this it also maintains the fertility of soil as it fixes the soil atmospheric nitrogen (Hosseinzadeh *et al.,* 2018). Nitrogen-fixing ability also has environmental benefits due to reduced emissions of nitrous oxide greenhouse gas. On average the mean nitrogen fixed by chickpea. is 40 kg/ha, however it can fix upto 125 kg/ha nitrogen in field depending on agronomy, precipitation, soil management, and inoculation. At global basis, it is cultivated in 56 countries and the total area is covered by app. 17.8 million hectares with an average production of 0.9t/ha. The major producer of chickpea are India, Pakistan, Myanmar, Nepal, and Bangladesh which are the Indian subcontinent but among all India contributes 69% of the total cultivated area with a production of 68%. In 1960 the production was less i.e., 0.6t/ha and at 2014 it was increased up to 0.006% only (Durdane *et al.,* 2021). The region where chickpea is produced is affected by various environmental stress such as heat stress, chilling and frost stress, drought stress (Pareek *et al.,* 2019). As the population is increasing day by day the need for food is also increasing but increasing global warming cause problems in the field of agriculture.

In regions of Asia, Europe, Africa and Australia due to abrupt changes in climate like extreme heat wave, drought, and floods the food production face major issues (Nadeem *et al.,* 2019). There is vast variation in precipitation, heat waves, and cold temperature due to the rise in temperature from the mid-21st century. Due to the occurrence of these changes, there is a huge impact on the production of chickpea which leads to yield loss. On an average drought and heat stress together accounts for about 50% yield loss (Farooq *et al.,* 2017). It was observed in Germany that rainfall is increased by 11% and 30% in the winter and summer season respectively. The temperature rises above 30°C which supports the pathogen and affects crop productivity and fertility. As the environment is changing plants also trying to adapt, moreover, the combination or alteration of diverse abiotic and biotic stress factors may further cause trade-offs between plant responses that are appropriate for adaptation to one stress but can enhance susceptibility to other stresses (Maqbool *et al.,* 2017). Chickpea is used as a rotational crop rather it is a crop individually on residual soil moisture, as it causes moisture stress at the end of the cropping system due to heat stress. During the reproductive stage, the heat stress is at its peak due to which the major yield loss we have to face is around 10 to 15%, and therefore, there is a decrease in the yield of 53kg/hectare whenever the temperature rises 1°C above the normal temperature. As the environment is changing day by day plants also try to change and adapt according to the changing climate (Pareek *et al.,* 2019).

A. Biotic and Abiotic Stress in Plants

In plants stress affects the growth and development. Stress can affect the plant morphologically and physiologically too and altered the gene expression, metabolism of cells, growth rates and results in decrease in the economic yield (Farooq *et al.,* 2017). If there is a sudden change in the environment it leads to stress, which is broadly categorized as biotic and abiotic stress (Fig. 1). The plants sometimes get more injury due to which the metabolic function of plants get disturbed. If the stress is less the plant can easily recover but if the stress is high the injury can lead to death because during stress the plant prevents the flowering, formation of seed and initiate senescence and this is the sign of plants which cannot tolerate stress (Farooq *et al.,* 2017). The common example of the stress-tolerant plant is desert plants also known as ephemerals (short duration plants), they flower in a few days and die (Pareek *et al.,* 2019).

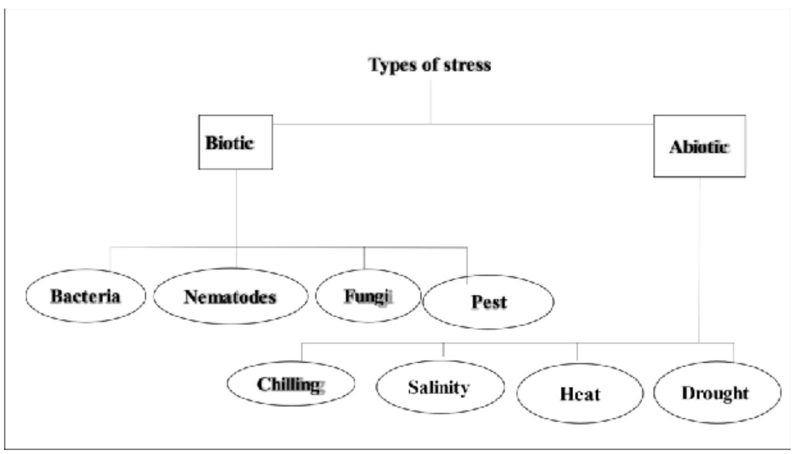

Fig. 1. Types of biotic and abiotic stress.

Biotic stress occurs due to biological agents such as disease, nematodes, insects, and pest while abiotic stress can be caused by any environmental change it may be physical or chemical. In the case of biotic stress, the pest and pathogen harm the plants by deriving the nutrients from the host plant and eventually it leads to death of plant (Bhaskarla *et al.,* 2020). Despite lacking the adaptive immune system plants can counteract biotic stresses by evolving themselves to certain sophisticated strategies. In the case of biotic stress it basically affects the process of photosynthesis, because the insects feed on leaves due to which the leaf area is decreased and the rate of photosynthesis decreases. In abiotic stress the plant can suffer from drought stress, water logging (excessive water), extreme temperatures such as heat, cold, and frost, salt stress, and metal toxicity which affects the growth, development, yield, and quality of crops. It was predicted according to today's condition that soon the water will become scarce as the level of freshwater decreases; therefore, it is necessary to develop a crop that is resistant to this stress and ensure food security (Mann *et al.,* 2019).

Chickpea is highly affected by abiotic stress like heat stress, drought stress, and salinity stress which leads to heavy yield loss. To minimize such losses the plant undergoes some morphological as well as physiological modification (discussed in Table 1) (Bhaskarla *et al.,* 2020). Plant responses to abiotic stresses fluctuate depending on growth/developmental stage, harshness, incidence, and span of exposure to the stress (Dresselhaus & Huckelhoven, 2018). While it is most sensitive during the reproductive phase, chickpea does display to some extent, sensitivity to abiotic stress at early vegetative stages which can reduce seed number. These abiotic stresses reduce yield largely through their effect on flower set, pollen viability, pod set/abortion, and retention, all being the key determinants of a seed number (Gaur *et al.,* 2019).

Table 1: Chickpea traits affected by abiotic stress.

Abiotic stress	Traits that are affected
Heat stress	Crop growth rate and duration Reproductive organs of chickpea The activity of enzymes within plants
Chilling stress	Integrity of membrane The activity of enzymes Process of germination and their establishment The process of photosynthesis
Drought stress	Duration of plant growth Growth of reproductive organs Accumulation of ABA in the pod and seed
Salinity stress	affects plants by toxicity caused by osmotic stresses and ions Salinity leads to a build-up of Na^+ and Cl^- in soil, consequently lowering the soil water potential as compared to the water potential of plant cells significantly reduced the plant height in chickpea at higher salinity
Heavy metal stress	low biomass accumulation, chlorosis, inhibition of growth and photosynthesis altered water balance and nutrient assimilation, and senescence, which ultimately cause plant death

B. Effect of drought stress in chickpea

Across the globe yield of chickpea is lost up to 40-45% due to drought stress and breeding techniques is applied for over two decades for drought tolerance in chickpea. According to the previous experiments performed by various researchers, it has been observed that several traits like early maturity to escape the drought stress, root morphology, partitioning rate, biomass of shoot, and yield of grain are the responses to drought stress. It was shown in table 1 how traits in chickpea get affected by drought stress (Kaloki *et al.,* 2019). This effect can be eliminated by using a tolerant variety of chickpea by using various genetic approaches, as the main objective is to recognize the genotypes by using methods known as screening. There is a short duration drought-tolerant variety that is ICC 4958 identified by ICRISAT (International Crops Research Institute for Semi-arid Tropics), this variety has some advanced root structure the length of the root is very long with a larger volume and because of this trait, this genotype is used much as a donor parent in the research of drought stress **(**Bhaskarla *et al.*, 2020). If there is a slight difference in the crop duration or yield potential then the effect can be seen in the yield of grain, as the short duration variety gives high yield as compared to long-duration variety when they are under stress conditions. To escape this stress and difference within the phenology various research has been conducted such as grain yield and time of 50% flowering. According to this method, they have selected 5 genotypes of most drought-tolerant and 20 genotypes that are highly sensitive to drought among a total of 211 genotypes. To identify the phenotype several imaging techniques are also there which are non-destructible and to measure the photosynthesis such as Lincoln, NE, LiCOR 6800) to measure chlorophyll like SPAD meter, Komica, Osaka for light there is an instrument known as a spectrometer, to develop a tolerant variety a pot experiment was performed in ICRISAT where 8 genotypes of chickpea were chosen and measured their canopy temperature by infrared thermometer under normal drought stress. It was observed that it was not sufficient for the field experiment should be conducted where CTD (canopy temperature depression) was calculated to observe the coming yield of crops under the condition of drought stress (Pushpavalli *et al.,* 2020). CTD recorded at the mid reproductive stage (62 days after sowing) was positively associated with grain yield. Therefore, drought tolerance breeding needs the understanding of crop developmental stage and intensity and duration of stress because plants can continue growing with a limited water supply (Kaloki *et al.,* 2019).

C. Effect of heat stress in chickpea

When the chickpea plant is exposed at a temperature of more than 30°C then it leads to loss of floral bud as well as open flower. At a temperature of more than 35°C to 39°C it leads to a loss in grain yield. At reproductive stage, if the plant is under heat stress, then there can be a major loss in yield because heat stress affects the sterility of pollen, and pod setting too, not only anther but pollen also showed some type of abnormalities like a number of locules, thickening of anther epidermis wall. At high temperatures both fertility of pollen and function of stigma are affected because heat stress triggers oxidative stress which leads to poor yield. Heat stress during the reproductive period affects grain yield due to poor pollen viability and reduced pod set (Coyne *et al.,* 2020). According to genotype, the plant can tolerate heat stress up to its tolerance capacity, basically due to heat stress the rate of grain filling decreases and ultimately the seed weight also decreased (Arif *et al.,* 2021). During the period of grain filling the concentration of sucrose and starch is also reduced under heat stress. The short-duration variety is much more tolerant to heat stress and shows better phenological traits as compared to the long-duration plant because the short-duration variety easily escapes the heat stress which leads to proper pod filling and high yield. Genotypes with lower canopy temperature depression i.e., 1 to 3°C had lower grain yield as compared to high canopy temperature depression i.e., >4°C (Mart *et al*., 2021).

D. Effect of salinity stress in chickpea

Salinity stress is one of the major issues that cause problems in crop growth and development, if there is a high concentration of salt present in soil then the crop can get affected by salinity stress as they disturb the balance of osmosis and cause secondary drought stress and the plant water uptake will be restricted (Muriuki *et al.,* 2020). Salinity stress disturbs the growth of the plant by influencing the hormones to make complex interactions and imbalance of nutrients. Salinity stress affects the overall growth of the plant along with grain yield its quality and its composition (Fatnassi *et al.,* 2018). For instance, photosynthesis in 100 legumes was reduced by salt stress due to the limited supply of carbon dioxide or salinity-induced reductions in photosynthetic pigments and disturbance in electron transport activity of photosystem II, the carbon dioxide availability reduced it limits the diffusion process via stomata as photosynthetic pigments and electron transport activity of photosystem II are influenced by specific toxicity of ion from over-accumulated Na+ and/or Cl– 104 and/or salinity-induced oxidative stress (Maqbool *et al*., 2017). The availability of carbon dioxide reduced and increases the chlorosis disease and leaves necrosis under salinity stress and triggers the senescence of leaves. Likewise, grain protein contents in grain legumes decline under salt stress due to reduced nitrate absorption from the soil solution and/or disturbed the metabolism of nitrogen in legume plants (Jha *et al.,* 2018).

E. Effect of chilling stress in chickpea

Chickpea is also affected by low temperature which is divided according to temperature i.e., -1.5 to 15°C. Chilling stress occurs when the temperature is below-1.5°C which affects growth and production. Due to chilling stress, the viability of pollen is suppressed, stigma receptivity is also reduced and pod setting will get delayed. Kabuli variety of chickpea are much chilling tolerant as the Testa is thin which allow the imbibition rapidly and due to which it is susceptible to chilling stress. Hence, due to high susceptibility, there is high leakage of electrolytes, chlorophyll loss, a decrease in the content of sucrose, and decrease starch accumulation. The emergence is delayed when chickpea is sown at low temperatures due to the longer time to accumulate the required minimum edge of approximately 115 growing degree days, and successive low temperature or frost events reduce the plant growth rate ultimately lengthening the duration of the vegetative growth stage and delay in flowering, podding and maturity. When the plant is at the reproductive stage it easily adapts to the low temperature as compared to when it is in the seedling stage because when the plant is at the seedling stage the pod will not set properly which leads to heavy yield loss (Yousefi *et al.,* 2018). To overcome this stress seed priming is one of the methods by which the effect can be reduced by enhancing the growth, water relation, process of photosynthesis activity of amylase, metabolism of sugar, the activity of the antioxidant enzyme. There is also the various breeding method by which the development of chilling tolerant variety is introduced, sometimes the plant easily adapts the climate change but to adapt to these changes they take their own time at that time there is a need to introduce breeding methods by which plant can become more susceptible to these stress condition (Hegde *et al.,* 2018).

F. Breeding in chickpea for stress-tolerant genotype

The plants which are mostly short duration can easily escape the drought stress as early flowering will be there due to which the plants will mature early. In a short duration crop, the plant will flower early i.e., 20 to 25 days early as compared to a late duration crop. This type of mechanism increases the yield of chickpeas. Some of the examples of early maturing variety are KAK2 and JG 11 in the southern region which has huge productivity. Early maturing Kabuli genotypes such as ILC3182, FLIP98-142C, ILC1799, ILC3832, FLIP98-141, ILC3101, and ILC588 under dryland conditions in Iran were identified as early maturing genotypes (Richards *et al.,* 2022). Hence being an early maturing variety easily escape the stress condition and as a result, the yield is high. The roots of chickpeas can utilize soil water even from a depth of 15 to 30cm. Total biomass of the root in the early growth stage i.e., end of the vegetative period, and seed yield under terminal drought showed a positive correlation (Coyne *et al.,* 2020). The deep root system of chickpea utilizes the subsoil water due to which the yield is optimum even in drought conditions. The biomass of the root and its depth is one of the traits which is a type of adaptation considered in chickpea, in the breeding line there are some varieties were introduced which are drought tolerant i.e., ICC 4958, and drought-sensitive too i.e., Anegre, and these varieties are discovered by researchers of ICRISAT (Kaloki *et al.,* 2019). These studies in different genotypes revealed that by breeding we can control the density of roots and morphological structure so that they can easily tolerate the plant along with high productivity as shown in (figure 2). Moreover, soil water manipulation at the reproductive stage must match crop phenology such as 50% flowering development of pod in order to utilize root traits to achieve drought avoidance in chickpea (Yousef *et al.,* 2020). There are many studies that have been conducted to make the plant more resistant to salinity stress. The seeds go through many screenings process, as the advancement in technologies has been increased such as genetic inheritance, evaluation techniques, software techniques, molecular markers, germplasm modification, and mapping. The majority of the plant processes which are having a role in salinity tolerance show continuous diversity, have a little inheritance, and are also affected by environmental factors. There are many techniques that include Mutation breeding, it is used to create variation in the genes of plants. A major key of this process is the identification of the individual with a target mutation which involves two important steps screening and mutant confirmation. In this process first, the seeds are treated with some mutagens like agent's gamma rays, chemical mutagens, x rays, and fast neutrons, after dividing the plants which have useful qualities are chosen for the next generation. Multi-location trials are conducted for evaluation and released as a new variety with use. Another method is DH production (double-haploid) which is done through a culture of anther, it is a very exciting tool that is used for improvement in the crop. It shortens the cycle of breeding and has high selection efficiency, fixation of homozygosity, and expression of recessive alleles suitable for breeding. This technology is found to be very efficient as it helps to fix favourable alleles to control the agronomical trait of plants (Singh *et al*., 2021).

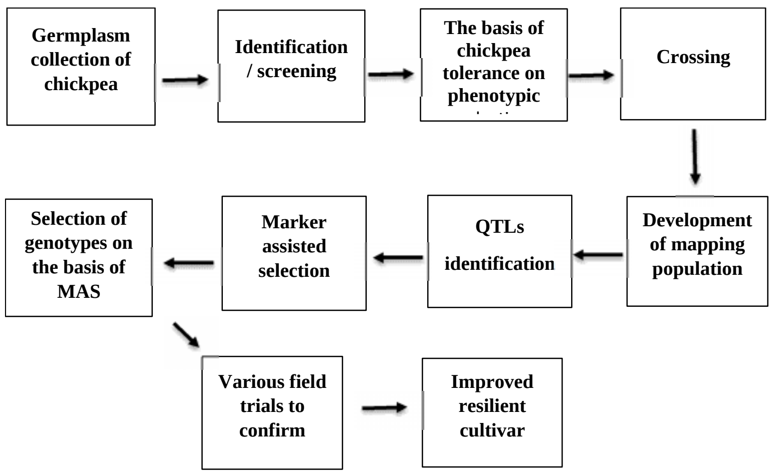

Fig. 2. The strategic approaches to developing resilient cultivars.

Similarly, an early maturing i.e., ICCV92944 is tolerant to heat stress. Under late sown conditions this variety is mostly preferred for the cereal-based cropping system. Early flowering with a long reproductive period is an important trait for heat and drought escape mechanisms. For the breeding program, various heat sensitive and tolerant varieties are developed. ICRISAT develop a set of recombinant inbred line by crossing two different genotypes i.e., ICC4567 × ICC15614 to study their response to heat stress under field conditions, and it was observed that pod set percentage was highly affected by heat stress (Kaloki *et al.,* 2019). In case of salinity stress, the root characteristics is the first line of defence in plants. One of the primary responses to abiotic stress such as high salinity is the disruption of the Na+ /K+ ratio in the cytoplasm of the root cells. The phytohormone abscisic acid (ABA) plays an important role during plant adaptation to environmental stress such as high salinity, drought, low temperature, or mechanical wounding (Richards *et al.,* 2022).

G. Adaptive traits in chickpea

In competition with weeds, the early vigour of chickpea is a very beneficial trait, but in regions, like semi-arid this feature is not much utilized as the crop will immediately get exhausted and the stored water will become scarce due to which plant will face terminal drought during the reproductive stage. But, in regions like Australia where there is a Mediterranean climate this trait is very useful because the cropping system fully depends on winter rainfall and this early vigour enhances the ground cover, decreases the run-off water, and reduces the evaporation rate by preventing moisture loss within the soil profile (Richards *et al.,* 2022). To induce this trait various conventional method is used, as these methods are labour-intensive and not much suitable for field trials. To adapt to the heat and drought stress roots are very helpful such as length and density of roots, their volume, and depth along with root mass. As we discussed earlier abiotic stress such as heat, drought, chilling, and salinity is the major factor that is responsible for the yield loss in chickpea but chickpea has some adaptive traits which are useful to tolerate this stress and some of the traits are developed by various breeding methods (Jha *et al.,* 2018). However, change is reliant upon the season, planting date, and water system and these mixes influence phenological improvement with sped-up advancement under late planting and dry circumstances, early chickpea lines that are full-grown under 85 days have been grown however these are by and large lower-yielding contrasted with the more drawn out length lines, and for the most part early flowering plants show biomass collection, level, and yield reduction and have fewer pods and seeds per plant than the late-developing plants. This may be on the grounds that they don't have adequate development time to amass acclimatizes for ensuing remobilization to the creating grain. The more limited vegetative development stage might possibly restrict biomass collection and arrangement of extra branches and podding hubs, while the more limited podding stage may be lacking for grain filling except if the pace of grain filling is altogether sped up. In chickpea, flowering and podding (regenerative and grain filling stages individually) are by and large the most basic stages impacted by unfriendly circumstances. Early life is an advantageous quality in chickpea, and it adds to weed intensity, water use productivity, and grain yield under specific developing conditions. In semi-dry conditions, for example, in India, early force is certainly not a great characteristic since yields will rapidly debilitate put away water causing a drought at the reproductive stage. In any case, in Mediterranean environments, for example, Australia where editing frameworks fundamentally rely upon winter precipitation, early energy qualities can work with crop development by upgrading ground cover, diminishing water run-off and vanishing by saving dampness in the soil profile for later use in the season. Early life is a versatile characteristic of dry season and chilling pressure in chickpeas Root attributes, for example, root length thickness, volume, root profundity, and root mass assume a basic part in drought and intensity transformation in chickpeas and a few QTLs controlling root qualities have been accounted for. Exact phenotyping of root attributes is tested since roots develop underground, and they are hard to recuperate from soil completely. Common methods for characterizing root traits in chickpea and food legumes are using polyvinyl chloride cylinder (PVC) growth systems, soil cores, semi-hydroponic system (Maphosa *et al.,* 2020).

CONCLUSION

The change in climatic conditions causes various stress conditions to the plant which hinders the proper growth and development of the plants. The major challenge in the production of chickpea is climate change as it affects production and productivity too. The yield of chickpeas is affected by the drought, high temperature, chilling effect, and high moisture content. These stress conditions like heat stress, chilling stress, salinity stress and drought stress are one of the reasons for yield and quality loss of chickpea. The breeding techniques help in pre-flowering or adapting the stress conditions by tolerating them.

FUTURE SCOPE

In present time, the drastically changing climate is the most serious threat to crop cultivation. In this scenario, development of climate resilient varieties is considered as the most judicial approach to sustain the productivity of agroecosystem. Crops like chickpea that are short in duration and less demanding as compared to most of the commercial cereals could be a good choice in the context of growing climate resilient cultivar to realise the end of zero hunger. This manuscript would be a helpful guide for breeders in devising chickpea improvement programme aimed at developing high yielding stable cultivars.

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Conflict of interest. None.

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