

Polyethism in the Case of Feeding, Construction, and Defense Behaviors of *Odontotermes formosanus* Shiraki

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Abstract – South of China always invaded by *O. formosanus* Shiraki. This species is one of the main causes of damage to the forests, crops, buildings, boats and even water preserving constructions like dams. In this paper we studied the main trees invaded by this species. *Cinnamomum camphora* was the main target for this species (33% of all the cases), along with *Sophora japonica* (21%), *Liriodendron chinensis* (11%), *Cunninghamia lanceolata* (11%) *Robinia pseudoacacia* (5%), *Magnolia denudata* (5%), *Metasequoia glyptostroboides* (5%), *Prunus mume* (3%), *Catalpa speciosa* (3%), *Ulmus pumila* (3%), and *Castanea sativa* (3%). The foragers ridden the tree were collected and a column charts depicted based on their head width. Based on the peaks in the column charts, five instars of workers can be predicted at the foraging sites. Three middle instars are most frequent workers at foraging sites. In addition the polyethism of foragers, workers and soldiers, have been investigated in the case of defense and construction. The results have shown that the workers with smaller head width have more potential to participate in construction behaviors especially breaking shelter tubes. Also, early defense behavior mostly has done by soldiers with smaller head width whilst the later after 50 minutes however the number of soldiers with bigger head width increased but the total number of soldiers plummeted.*

Keywords – Isoptera, Termite, *Odontotermes Formosanus* Shiraki, Feeding Behavior.

I. INTRODUCTION

Termites or white ants, in fact they are not related to ants, are eusocial insects and taxonomically were classified in Isoptera. Recently they are classified as the epifamily Termitoidae, of the cockroach order Blattodea [1]-[2]-[3]. As similar as other Hymenoptera, bees and ants they are living in society with different members or cast that each one has its own special duty in the nests [4]. In usual, termites are using dead plants or animal feces as

a source of food, so, their key role in ecology cannot be ignored [5]. But some of them are known as pest in forest and agriculture economy. Tropical and subtropical regions are host of these highly organized societies of insects [6]. The importance of diet in termites' taxonomy is very important. Denovan et al at 2001 divided the termites into four feeding groups based on their food preferences. In addition to feeding habits, the mandibles also are different in. The marginal teeth have different pattern based on the diet. Based on teeth pattern the mandibles are divided into two groups, grinding (milling) and pounding (pestle and mortar) [5].

Subterranean termites such as *O. formosanus* Shiraki are one of destructive species in south of China. In addition to China, Myanmar, Thailand, Vietnam are infested by this kind of termites. Variety of plants can be used in their diet; they can use shrubs and weeds as a source of food. Furthermore, species such as Chinese fir, cedar pond, Magnolia, black wattle, eucalyptus, paulownia, camphor, sassafras, Schima, oak, chestnut and more than 70 other plant can be attacked by this kind of termite. They cannot be only hazardous for forest trees, but also fruit trees, sugar cane, jute, herbs, underground cables, reservoirs dams, and water conservancy [7]-[8]-[9]. As similar as other species of termites, the foraging workers in *O. formosanus* Shiraki are the main destructive castes in the nest. The fact is that the workers are responsible for feeding other caste. Their head structure and mandible make the good gnawer at the foraging sites [10]. They are digesting the cellulose and pass it to other members of the nests through their mouth or anus. This trophallaxis behavior is true about queen even. First generation only is fed by queen and king and after that this important duty will be transferred to worker [11].

Division of works or polyethism among the workers is one of interesting subjects since ancient times. Bozorgmeher a scholar and minster of Sassanid dynasty in Persia (498-579) tried to understand the secret of polyethism among honey bees. Polyethism is one of the important phenomena in social insects especially termites [12]. We recently found that foragers with size of middle head width are the main foraging workers in *O. formosanus* Shiraki [13].

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In this paper we studied the foraging sites of *O. formosanus* Shiraki. Main targets of the foragers have been recorded and the foragers, workers and soldiers, have been collected and checked for finding any polyethism among them. In addition the defense and construction behavior of the termites have been investigated to see if there is any division of works subjected to this.

II. MATERIALS AND METHODS

Nanjing Forestry University (NFU), located in the east of Nanjing, at the foot of Zijin Mountain and east of Xuanwu Lake (32° 4' 50.66" N, 118° 48' 41.06" E), was the study site. All the termites captured in a sunny day between 10Am-2 Pm with temperature of 20, humidity of 50 and a breeze blowing (0.5 Km/H). Hot damp summers and cold damp winters with short spring and fall are the main characteristic seasons in Nanjing. Finding shelter tubes on the trees considered as a sign of foragers of a nests. Making a breach in the tube gently (tweezers can be used) and then by the means of smooth painting brush samples collected into a plastic container (11 cm in diameter, 4 cm high) with a moist filter paper in it. Foragers of each nests collected into one plastic container. After collecting the samples, name of the invaded species recorded.

Samples taken to the lab and mud particles removed from them, then transferred into glass vials containing FAA (37% formalin: acetic acid: ethanol=6:1:16). Foragers kept into FAA over night. Then replace the FAA with 70% alcohol.

To measure head width (exactly after antenna toward back side of the head) of the samples, JSZ6S (20030568) microscope (manufactured by Nanjing Jiangnan Novel Optics Co.,Ltd) with a camera (JIFEI) (manufactured by Nanjing JIFEI Technology Co.,Ltd) assembled on it has been used. The microscope was connected with a computer. JIFEI software helped us to measure and capture photos in the computer. Microsoft Excel has been used to calculate Average and Standard Error. After measuring the head width, the data has been loaded into Microsoft Excel and column charts made using head width and frequency of them as x and y axis respectively. Based on the peaks, workers and soldiers have been classified into different groups [14]-[15]-[16]-[17]. For division of the groups we consider a gradual rise ended with a peak and a gradual down. So a sudden rises or falls did not consider as groups. Also, lowest peak is reflected as starting of one group.

In the case of studying polyethism among trees, the nests divided based on the tree they had been hosted. Then, head width measured and similar criteria used to divide the foragers.

III. RESULTS AND DISCUSSION

Cinnamomum camphora (33%), *Sophora japonica* (21%), *Liriodendron chinensis* (11%), *Cunninghamia lanceolata* (11%), *Robinia pseudoacacia* (5%), *Magnolia denudata* (5%), *Metasequoia glyptostroboides* (3%),

Prunus mume (3%), *Catalpa speciosa* (3%), *Ulmus pumila* (3%), and *Castanea sativa* (3%) were highly infested by *O. formosanus* Shiraki.

C. camphora was infested by total number of 1814 foragers, 1790 workers and 24 soldiers. Average head width of the workers and soldiers were 1.46mm (standard error: 0.001) and 1.39mm (standard error: 0.01) respectively. Based on the peaks in column chart of the working foragers, the workers can be divided into seven groups, 1.29-1.34 mm, 1.35-1.4mm, 1.41-1.47mm, 1.48-1.52mm, 1.53-1.57mm, 1.58-1.62mm, and 1.63-1.67mm. In average every 0.04mm we have one group of workers (Fig.1).

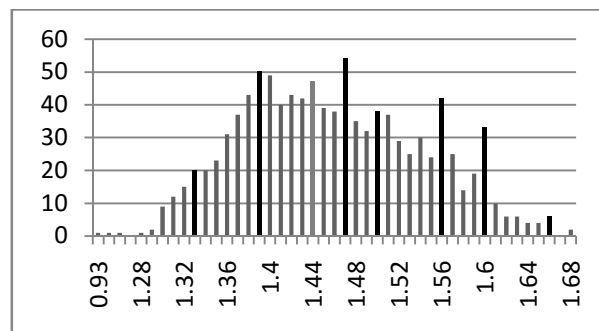


Fig.1. Column chart of the working foragers that infested *C. camphora*. Peak of each group has colored in black. A wide range of foragers from 0.9- 1.7mm can be seen in the chart.

S. japonica, total number of 1068, 1064 workers and 4 soldiers, invaded this species. Average head width of workers and soldiers were 1.44mm (standard error: 0.001) and 1.36mm (standard error: 0.07) respectively. A column chart has been made based according to head width of working foragers. Based on the peaks the workers divided into 6 groups, 1.27-1.32mm, 1.33-1.37mm, 1.38-1.42mm, 1.43-1.48mm, 1.49-1.52mm, and 1.53-1.57mm. The average distance between each group of workers is about 0.045mm (Fig.2).

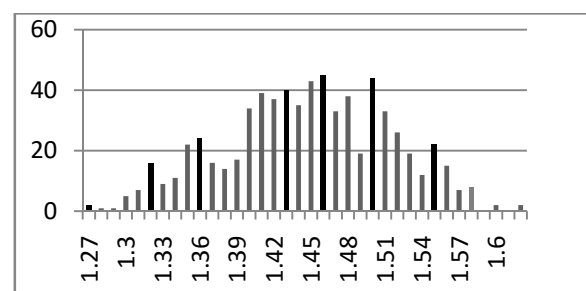


Fig.2. Column chart of the working foragers that ridden *S. japonica*. The middle groups of workers peaks are more close to each other. It means the growth rate is very high.

L. chinensis, in this case a broad range of workers with variety of head widths can be seen. Total number of 622 workers and one soldier has been captured in the shelter tubes. Average head width of the workers was 1.45mm (standard error: 0.005). Based on the chart the workers can be divided into 5 groups, 1.25-1.31mm, 1.32-1.38mm,

1.39-1.48mm, 1.52-1.63mm, and 1.64-1.70mm. It means that each group has about 0.072 distances with next group in average (Fig.3).

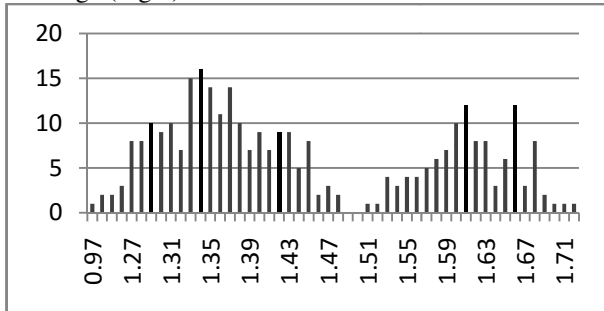


Fig.3. Column chart of the working foragers that swarmed *L. chinensis*. This tree species also was as similar as *C. camphora*. A broad range of workers infested the tree.

C. lanceolata, 200 workers and 2 soldiers were among foragers that attacked this tree species. Average head width of the workers was 1.35mm (standard error: 0.002). Based on the column chart two groups of workers can be seen among foragers, 1.32-1.37mm, and 1.38-1.42mm. It means there is 0.045 intervals among the workers groups (Fig. 4).

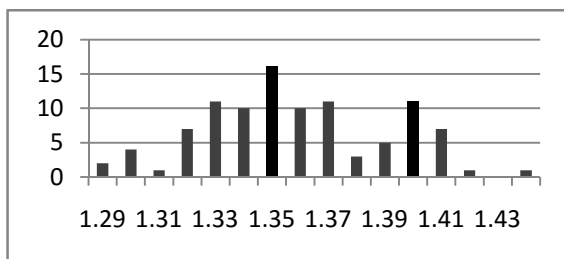


Fig.4. Column chart of the working foragers that infested *C. lanceolata*. As the number workers decreasing, head width range of foragers decreasing too.

R. pseudoacacia, total 288 foragers found on this tree species. Average head width of workers was 1.52mm (standard error: 0.003). Only one of them was soldier and rest of them was workers. Only one group of workers can be seen based on the column chart (Fig.5).

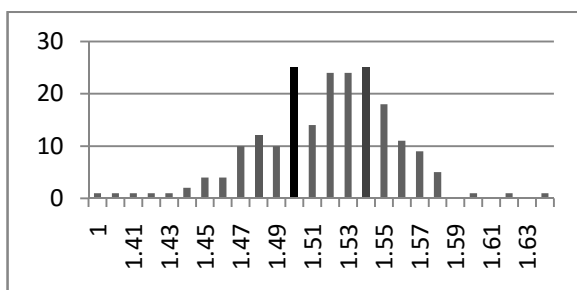


Fig.5. Column chart of the working foragers that ridden *R. pseudoacacia*. The majority of the workers 1.4s and 1.5s mm head width.

M. denudata, 202 workers and one soldiers ridden this tree species. Average head width of the workers was 1.4mm (standard error: 0.005). Only one group of workers can be recognized based on the column chart (Fig.6).

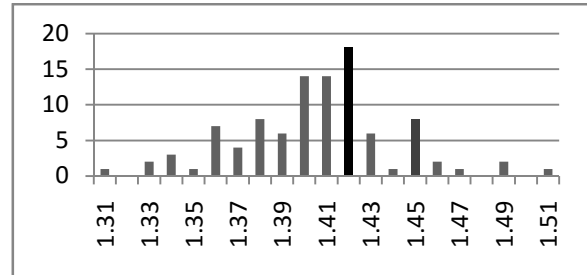


Fig.6. Column chart of the working foragers that infested *M. denudata*.

M. glyptostroboides, 55 working foragers and no soldier have seen invaded this tree species. Average head width of the foragers was 1.44mm (standard error: 0.006). Based on the column chart, only one group of workers has invaded this tree species (Fig.7).

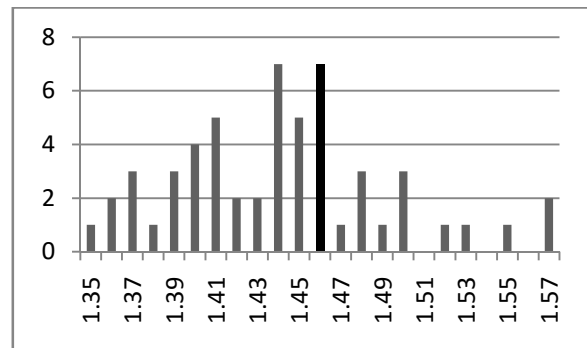


Fig.7. Column chart of the working foragers that invaded *M. glyptostroboides*.

P. mume, 80 workers swarm to this tree species and there have not seen any soldiers on the tree. The average head width of the foragers was 1.54mm (standard error: 0.004). As it can be understood from the chart, in this case also only one group of workers can be seen (Fig.8).

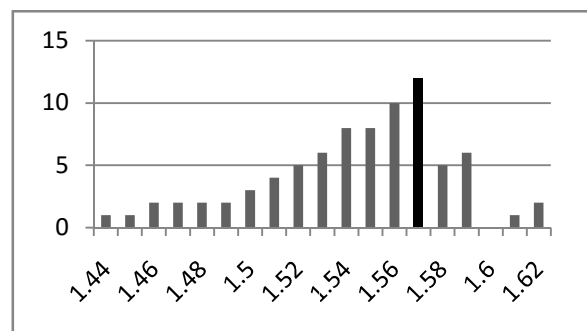


Fig.8. Column chart of the working foragers that invaded *P. mume*.

C. speciosa, 202 workers and one soldier were among the invaders to this species. Average head width of the working foragers was 1.43mm (standard error: 0.002). Only one peak can be seen in the chart, so, only one group is available (Fig.9).

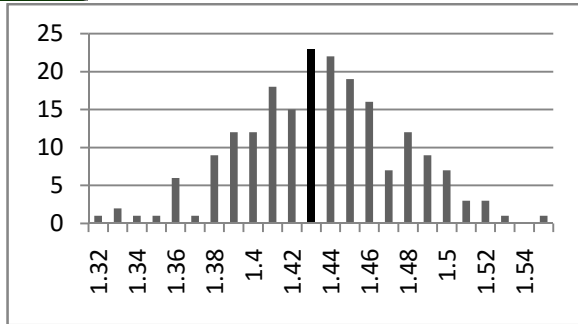


Fig.9. Column chart of the working foragers that invaded *C. speciosa*.

U. pumila, total number of 173 foragers found on the tree, 172 workers and one soldier. Average head width of the workers was 1.53mm (standard error: 0.004). If the non sense data been removed, only one peak can be seen in the chart.

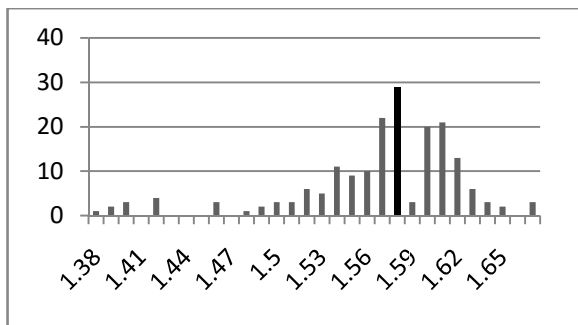


Fig.10. Column chart of the working foragers that invaded *U. pumila*. Some of the data are so far so away to be considered.

C. sativa, 72 foragers found at the foraging site. Average head width of the foragers was 1.52mm (standard error: 0.005). The chart is showing that the only one group of workers can be seen.

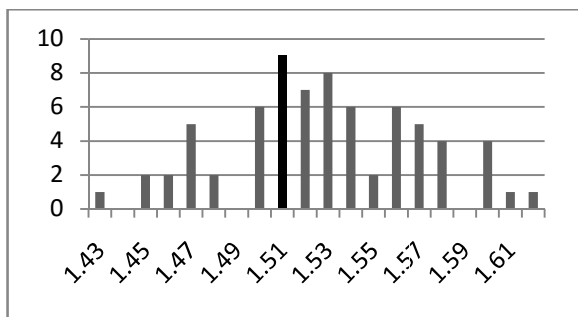


Fig.11. Column chart of the working foragers that invaded *C. sativa*.

In addition to feeding behavior, the construction of breaches has been studied. Subject to construction and defense, 1246 workers plus 25 soldiers trapped. The workers with smaller head width usually take part in the construction behavior. As it can be seen in figure 1 about half of the workers who participate in construction have the head width between 1.3-1.4. And it is interesting that after 50 minutes number of workers with bigger head

width will increase. Percentages of worker with head width between 1.5-1.6 will increase from 9% after 10 minutes to 19% after 50 minutes. Number of workers participated in repair behavior were dramatically different. Total number of workers in early (10 minutes) and late repair (50 minutes) were 1246, 39.4% of workers take part in early and 60% in late repair (Fig a, b).

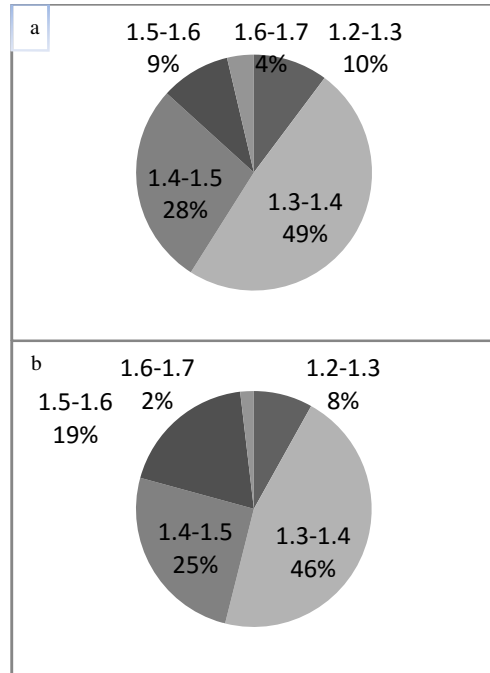
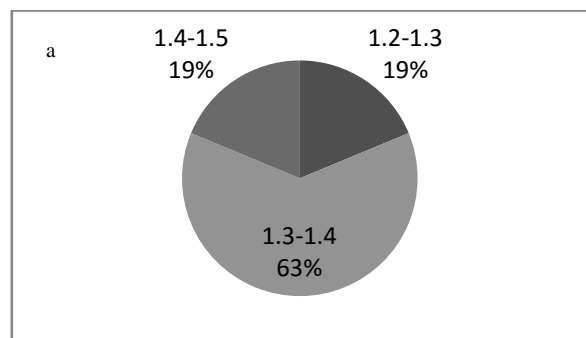


Fig.12. (a) Percentages of different group of workers head width after 10 minutes. (b) Percentages of different instar workers head width after 50 minutes.

Head width of the soldiers in the event of defense increased. 25 soldiers captured during construction and defense behaviors. It means 2 % of all the total population were soldiers. A glance will tell us that the head width is increasing during defense behavior. In fact, after 10 minutes soldiers with 1.3-1.4 (SS2) are the main ones in defense behavior, whilst at the end of this behavior, the soldiers are mainly with head width of 1.4-1.5. It should be mentioned that however the head width increased, but number of the soldiers decreased form 16-10.



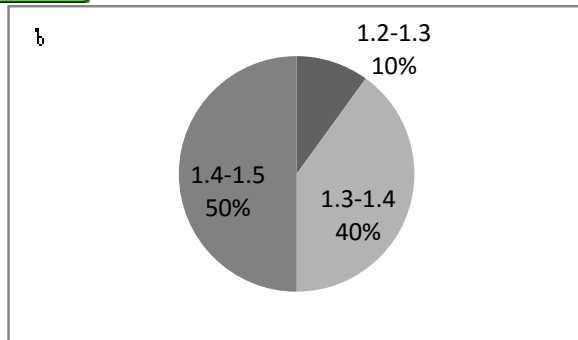


Fig.13. (a) Soldiers Head width after 10 minutes during construction and defense behavior. (b) Soldiers Head width after 50 minutes during construction and defense behavior. As It can be seen from the picture in first 10 minutes, number of soldiers with middle head (1.3-1.4) width (1.3-1.4) are high, whilst after 50 minutes the number of soldiers with bigger head width (1.4-1.5) will be increased.

IV. DISCUSSION

Forest protection against *O. formosanus* is one of the main factors in forest management in China. In one research has done by Kasseney et al. (2011), eight different species used to study the eating preference of *O. formosanus*. They noticed that *Magnolia denudata* Desr with 75% and *Elaeocarpus glabripetalus* Merr with 41% were the most preferred solid baits for them on the other hand for crude flour, *E. glabripetalus* (97%), and *Quercus variabilis* Blume (92%) were most favorite ones [18]. In another study has done in institute of fruit and tea in Wuhan, Appel et al. (2012) demonstrated that *C. camphora* was the most favorite species for them as habit [7]. Our result highly suggests that *O. formosanus* has a very vast range of diet. The above studies on *O. formosanus* Shiraki diet were amazing. However above studies only test a limited numbers of plant species, we analyze their diet in the foot of Purple Mountain with variety of species, 621 plant species from 383 genera and 118 different families, including 78 cultivated species. The results can be very important in forest preservation management and economy. Based on the foragers' column charts and comparing the picks of the charts, it can be expected that at some points the probability of having peaks are more than other points, 1.32mm, 1.42mm, 1.46mm, 1.5mm, and 1.66mm. If we consider each of the peaks as one instar for the foraging workers, five instars of workers can be predicted at the foraging sites. As it can be interpreted from column charts, in the middle instars the workers grow very fast and the peaks of instars are very close to each other. Distance between first and second instar is 0.1mm but the middle instars distances is only 0.04mm. The distance between last instar with later one is even bigger, 0.16. It means as the workers become bigger they grow very slowly. Furthermore, all of the charts are bell shape and it means the workers with middle head width are the main foragers and it does not matter which kind of tree species the workers are attacking. Thus, if we consider the workers with middle head width as the middle

age workers, the Achilles hill of a colony in the case of foraging is middle aged workers.

As well, in the event of construction, workers with smaller head width (1.3-1.4) are the most vigorous ones. This result is supported the hypothesis by Jones 1980 for *Nasutitermes Costalis* that Small worker 2 (SW2) are the most active workers during gallery repair [19]. And it is not supporting the postulation by McMahan (1970) and McMahan (1974) for *Nasutitermes costalis* that third stage large workers (WL3) are the main workers to the site of repair [20]-[21]. In another paper by Watson and McMahan in 1978 on *Drepanotermes*, it was mentioned that W4 and W5 workers (Large worker) will increase during repair [22], but our result did not prove that. However, as they said, the number of soldiers with bigger head width increased at the repair site. It is interesting that in repairing the shelter tubes after 50 minutes number of large workers (1.5-1.6) increased up to 10 percents.

Many publications implicated that workers are protected by soldiers during foraging [23]-[24]-[25]-[26]. However the story about *Nasutitermes corniger* (formerly *N. costalis*) is different the soldiers recruit the workers after discovering the best place for foraging [27]. It was fascinating that 10 minutes after breach in the shelter tubes number of small soldiers (1.2-1.4) are 82% of all the soldiers. This idea is parallel with a paper has published by Kriston et al. (1977) That mentioned small soldiers are usually attracted to the site of intruders [28]. Our result can prove proposition by McMahan (1974) that number of small soldiers were more when they punctured shelter tubes [21]. However at the end of construction again the number of soldiers with bigger head width (1.4-1.5) increased dramatically up to 50% of all the soldiers.

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