بسم الله الرحمن الرحيم

***The editorial board is pleased with the publication of the second issue of University of Ha'il-Journal of Science (UOHJS). It is with great hope that this journal will be a valuable tool in its field of specialization. This follows the efforts of the University of Ha'il in promoting scientific research and facilitating all researchers to present their scientific visions and ideas, which in turn is expected to enrich knowledge in all scientific fields including: basic Science (Biology, Chemistry, Mathematics, and Physics), Computer Science and Engineering.***

***The second issue contains articles from various scientific fields including: Biology, Mathematics and Engineering.***

***I would like to sincerely thank all the researchers who have contributed with their scientific productions, and also to the journal's editorial board for their efforts in issuing this volume, and to the University Administration for its support of the journal. I pray to Allah that this journal will be a significant addition to the field of scientific researches.***

***Allah bless,***

***Editor-in-Chief***

***Dr. Monif M. AlRashidi***

## University of Ha'il-Journal of Science (UOHJS)

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### Aims and Scope

*The "**University of Ha'il-Journal of Science (UOHJS)**" is an international journal for sciences. This journal is published by the University of Ha'il, Kingdom of Saudi Arabia. The scope of the journal is to publish peer-reviewed original research papers, short communications and reviews. The emphasis is on all scientific field including basic Sciences (Biology, Chemistry, Mathematics, and Physics), Computer Sciences and Engineering. The Journal is published in English language only. The Journal is edited by an international group of eminent researchers. UOHJS is published two issues (January, June) per year. Submission to the Journal is based on the understanding that the article has not been previously published in any other form and is not considered for publication elsewhere.*



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- Six keywords for indexing purposes (full papers only);
- Name of corresponding author, to whom proofs will be sent;
- Running title of no more than 45 characters.

2. **Abstract**: of not more than 250 words;
3. **Introduction**;
4. **Materials and Methods**;
5. **Results**;
6. **Discussion**;
7. **Acknowledgements**;
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SCOTT, G. (2005) Essential Animal Behavior. Blackwell Science.

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ROTHSCHILD, M., VON EUW, J., REICHSTEIN, D., SMITH, D. & PIERRE, J. (1975) Cardenolide Storage in *Danaus chrysippus* (L.) with Additional Notes on *D. plexippus* (L.). Proc. R. Soc. Lond. B Biol. Sci. 190, 1-31.

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# Distribution of Dominant Weed Species on Wheat (*Triticum aestivum* Lam.) and Alfalfa (*Medicago sativa* L.) Fields in Ha'il Region, Saudi Arabia

*Ahmed Alghamdi [1], Sherif Sharawy and Khalil Mseddi[2]*

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***ABSTRACT*:** This study was carried out on cultivated alfalfa and wheat fields in Ha'il region, at the northern zone of Saudi Arabia. It aims to invent the weed flora distributed in these fields and their life forms in order to create a data base of weed infestation degree. A total number of ninety seven weed species belonging to twenty seven Angiospermic families and eighty one genera were recorded in this study. The most dominant family in the current weeds' inventory was Poaceae (22.68 %) followed by Asteraceae (16.49 %), Chenopodiaceae (9.28%) and Brassicaceae (7.22%) respectively.

This study also shows that the most abundant weeds in alfalfa and wheat fields belong to the Therophytes group with a dominance of 73.2% of the total species, followed by Chaemophytes with a rate of 16%. Current weed inventory shows that twenty six weed species were first-recorded; among them sixteen species belong to Poaceae family. The most common weed species recorded in wheat fields were *Lolium multiflorum*, *Polypogon monspeliensis* and *Chenopodium album;* whereas the most dominant weed species on alfalfa fields were *Cynodon dactylon*, *Malva parviflora*, and *Portulaca oleracea* .

**Keywords:** weeds, flora, *Medicago sativa*, *Triticum aestivum*, inventory.

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## 1. INTRODUCTION

Generally speaking a weed is considered as a harmful plant species. However, plant taxonomists would not agree completely on this perception as they believe a weed plant could be considered undesirable in a particular situation, but might be a valuable crop in some other ones. It can be suggested that a weed is any plant species that grows or reproduces aggressively, or it is invasive outside its own natural environments (Jules, 1979).

As a broad general definition, weeds are unwanted plants that are competitive, pernicious, persistent, and have a negative impact on the agricultural activities. Weeds grow in association with agricultural crops causing significant decline in yields through their competition with crop plants for sunlight, space, nutrients...etc. (Dangwall ***et al.***, 2010). Potentially real new weeds are often neglected until they are largely naturalized and have a negative impact on environment and agricultural production (Waterhouse, 2003, Mseddi ***et al.***, 2017). Because of the huge advancement and interactions between sciences, it is somewhat difficult nowadays to describe the weed concept. The current research would go along with the concept of weed that is used in the sense of non-useful plant or unwanted plant as well as a plant out of its own habitat as suggested by many authors such as Hussain ***et al.***, (1988) and Rajput ***et al.***, (2008).

Most probably the heaviest loss caused by weeds results from their competition with crops for water, light and mineral nutrients. Weeds may cause more loss to agricultural crops than plant diseases, insects and pests (Dangwall ***et al.***, 2010). Therefore, many methods of weed control have been adopted such as chemical, mechanical and biological, but before the use of any of these methods it is necessary to identify the weed itself first.

Every country should build up a data base concerning diversity, and distribution of its weed inventory. Weeds should be identified whether they are native or exotic, invasive. In Saudi Arabia, various studies were reported to document the weed flora of the country such as (Parker, 1973; Chaudhary and Al-Howaishel, 1980; Chaudhary ***et al.***, 1981; Chaudhary and Zawawi, 1983; Chaudhary and Akram, 1987; Basahy and Monawar, 1994; Al-Yemeny, 1999). However, at the regional level, only the weeds of Al-Qassim region (El Ghazali and Al-Soqeer, 2013) were documented.

The current research aimed to add new reports on weed flora in Ha'il region which is considered to be the fourth largest region in Saudi Arabia. Ha'il region is located between 25° 35´ and 29° 00´ N longitudes and 39° 01´ and 44° 45´ E latitudes and covers an area of 118.322 $km^2$ and is bordered to the north by Al-Jauf and Northern Frontier, to the south by Al-Qassim, to the east by the Central and Eastern regions and to the west by Tabouk and Al- Madinah AlMonawarra regions. Although the importance of Ha'il region in terms of location, space and environmental characteristics, a few number of researches have carried out to studies on the natural vegetation of this region including (Chaudhary, 1983; Collenette and Tsagarakis, 2001; Al-Turki and Al-Olayan, 2003; Sharawy and Alshammari, 2009; El-Ghanim ***et al.***, 2010; Alshammari and Sharawy, 2010; Llewellyn ***et al.***, 2011). However, to the best of our knowledge the current research is the first of its kind that has been conducted on Ha'il's weed flora.

Although, alfalfa and wheat are the main crops that grow on a large scale in Ha'il region, famers are facing a serious problem which is the spread of weeds on their farms causing a severe damage of the productivity of their crops. Thus, the current study should offer an important step towards the control and the management approaches of the weeds in Ha'il region through the proper identification of their diversity.

This study is principally a taxonomic study that aims to identify, count weeds at Ha'il Farms, and to highlight the extent of their diversity. The results presented in this work are believed to be the first contribution to study the weeds diversity of the alfalfa and wheat fields in Ha'il region, and thus to increase our knowledge of the plant diversity of the region.

## 2. MATERIALS AND METHODS

Several field surveys were conducted in Ha'il region, Saudi Arabia in the period from October 2014 to May 2016, covering winter and summer seasons. The specimens were collected from many different sites representing different ecological habitats within the study area (Fig. 1). In each collection site, 2-3 agriculture farms were surveyed. For every weed species, 3-5 samples were collected and their herbarium sheets were developed, following the standard techniques. A voucher specimen has been deposited in the Herbarium of the Biology Department, Faculty of Science, University of Ha'il. The weed species were identified according to Zohary (1966, 1972), Mandaville (1990), Heemstra ***et al.*** (1990), Chaudhary (1983, 1989, 1999, 2000), Migahid (1996), Al-Eisawi (1998),Collenette (1998, 1999) and Al-Turki and Al-Olayan (2003). The life form (LF) was identified for each species according to Raunkiaer's system of classification (Raunkiaer, 1934).The families of the weed species are arranged in alphabetical order according the classification system proposed by Cronquist (1981), following the scientific names of the weed.

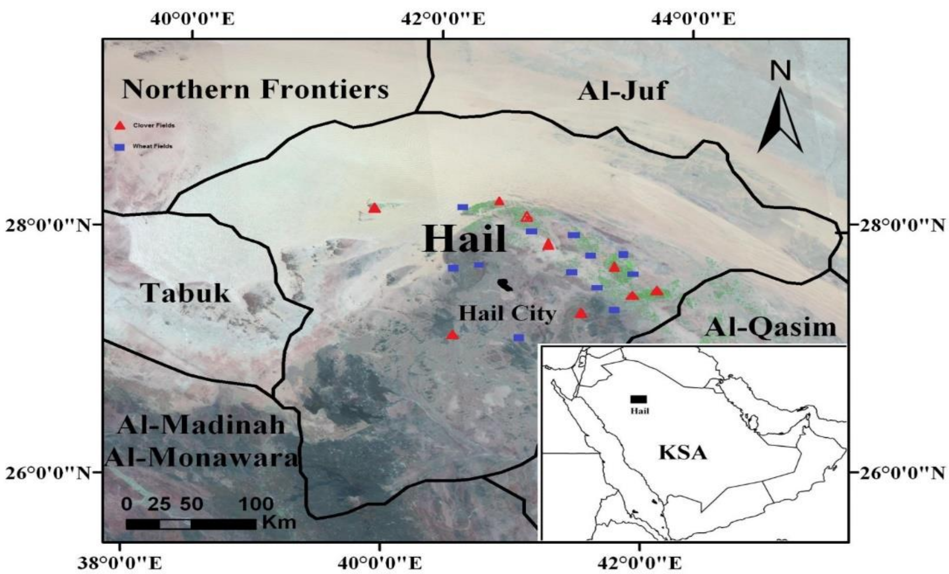


**Fig. 1:** Collection sites in Ha'il region, Saudi Arabia

## 3. RESULTS

In the current research, 24 different alfalfa and wheat fields in Ha'il region, north central of Saudi Arabia were surveyed and 97 species of weeds belonging to 81 genera from 27 families were collected, and identified (Table 1). The floristic analysis showed that dominant weeds in this study are annual herbs, while the lower group lies in the shrub category where only 4 species were recorded

(*Anvillea garcini*, *Rhanterium epapposum*, *Zilla spinosa* and *Withania somnifera*) (Fig. 2).

More than 65% of the recorded weed species belong to 5 species rich families. The largest families in terms of numbers of genera are Poaceae (20) followed by Asteraceae (12), Chenopodiaceae, Brassicaceae (6 for each), Fabaceae (4), Caryophyllaceae, Polygonaceae and Zygophyllaceae (3 for each), Aizoaceae, Boraginaceae, Euphorbiaceae, Orobanchaceae and Solanaceae (2 for each), while fourteen families are monogeneric.

The floristic composition showed that members of the family Poaceae dominate the weed plants of alfalfa and wheat fields in Ha'il region (22 species), followed by Asteraceae (16 species), Chenopodiacea (9 species), Brassicaceae (7 species) and Fabaceae (5 species), while the other thirteen families are monotypic (Fig. 3).

**Table 1:** Floristic composition of weeds recorded in alfalfa and wheat crops at Ha'il region.

| Plant groups | Families | Genera | Species |
|---|---|---|---|
| **Angiosperms** | | | |
| - Dicotyledons | 25 | 60 | 74 |
| - Monocotyledons | 2 | 21 | 23 |
| **Total Number** | 27 | 81 | 97 |

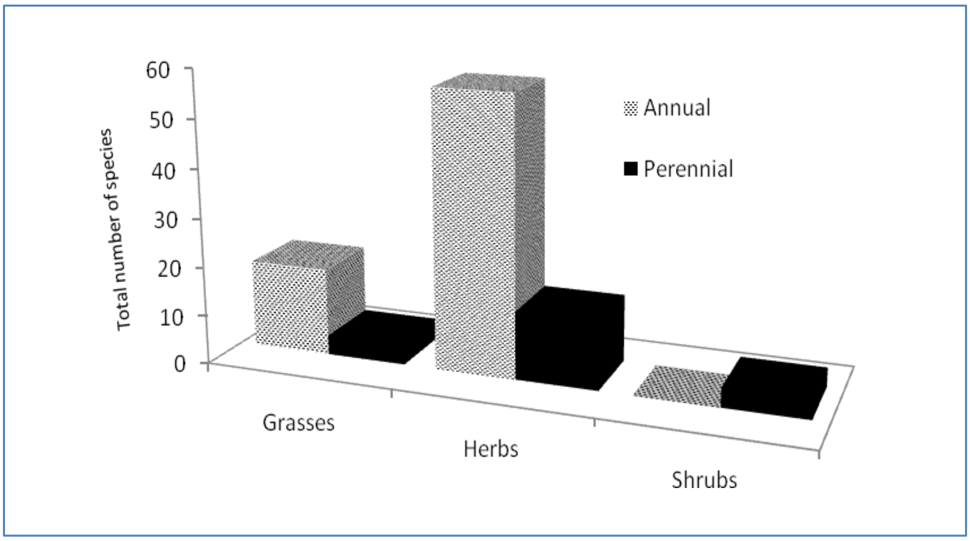


**Fig. 2:** Pattern of weeds recorded in alfalfa and wheat fields.

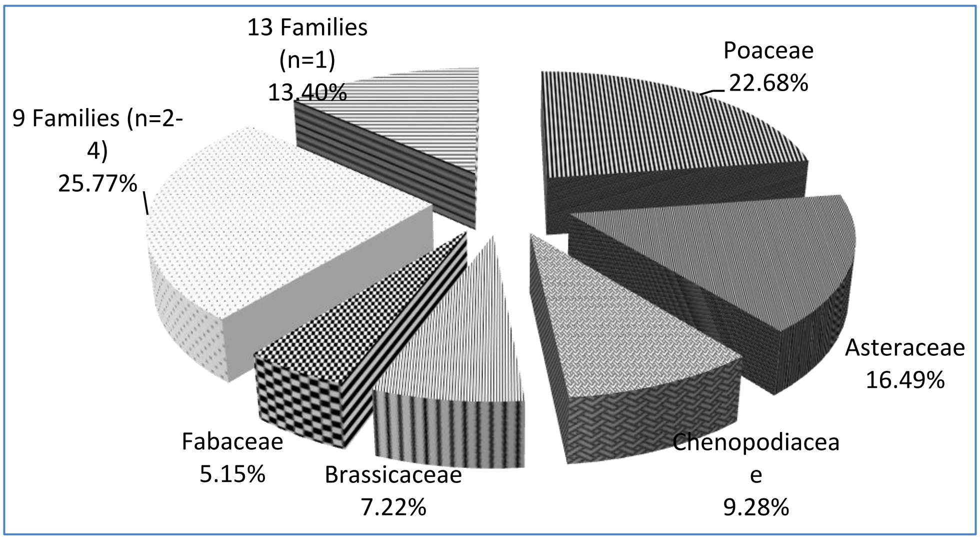


**Fig. 3:** Diagram of the floristic composition showing 5 species-rich families (n= number of species).

The life form (LF) was identified for each species according to Raunkiaer's system of classification (Raunkiaer, 1934). Thus, it is found that the most frequent life form class was Therophytes which represent 72.16% species of total weed plants recorded in both alfalfa and wheat fields, followed by Chaemophytes (16.49%), Phanerophytes (5.15%), Parasites (4.12%), while the least frequent life form class was Hemicryptophytes (2.06%) (Fig.4).

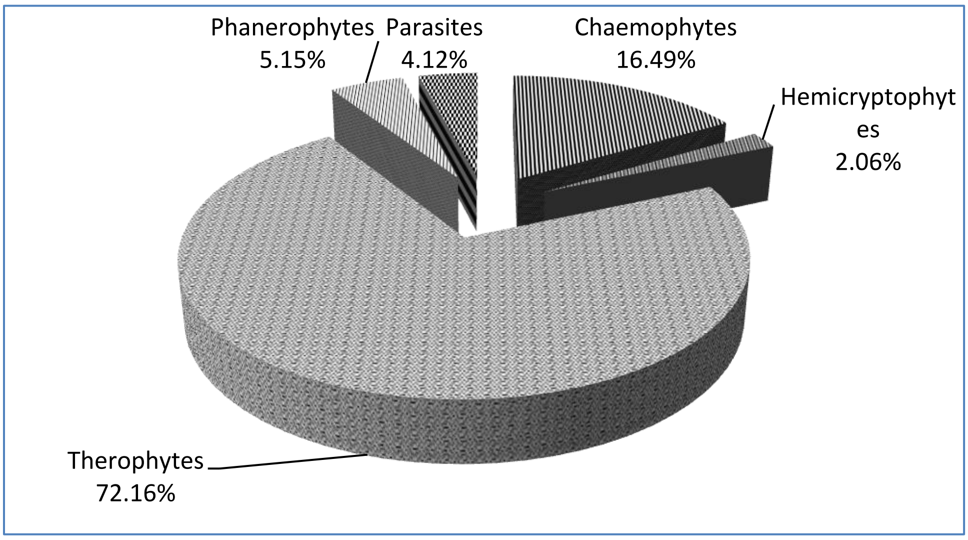


**Fig. 4:** Percentage of life forms for the weeds found in alfalfa and wheat Fields.

The floristic analysis of the weeds shows that 97 weed plants classified into 81 genera belonging 27 families were recorded in the alfalfa and wheat fields in Ha'il region. Among these recorded species, dicotyledonous comprised 74 species of 60 genera split into 25 families, while monocotyledonous comprised 23 species of 21 genera distributed over 2 families which are Liliaceae and Poaceae. Most of these recorded species were collected from alfalfa fields (95 species) while, in wheat fields only 38 species were collected. Among these species 36 species were recorded as common weed species in both crops and thus only 2 species (*Cutandia dichotoma* and *Lolium temulentum*) were collected from wheat fields (Table 2).

The species which are very common, and are found in all the fields of alfalfa and wheat crops are mostly herbs. It is possible that seeds of these weeds distributed on farms through the cattle manure, which is commonly used by local farmers in the studied area. *Amaranthus lividus, Launaea resedifolia, Senecio flavus, Sonchus oleraceus, Heliotropium digynum, Sisymbrium irio, Chenopodium murale, Malva parviflora, Cynodon dactylon, Rumex vesicarius, Portulaca oleracea, Anagallis arvensis* and *Tribulus terrestris* were recorded to be the most widespread weeds in alfalfa fields. While, *Calendula micrantha, Melilotus indica, Chloris virgata, Cynodon dactylon, Eragrostis barrelieri, Lolium rigidum* and *Polypogonm onospeliensis* were recorded as widespread species in wheat fields. Moreover, four species (*Cuscuta planiflora, Cistanche violacea, Orobanche cernua* and *Orobanche ramose*) were found as the major parasitic weeds occupying the agriculture farms in Ha'il region.

## 4. DISCUSSION

The floristic analysis of weeds recorded on alfalfa and wheat fields in Ha'il region showed that the annual herbs dominate the shrubs. Some of these findings were recorded previously by Al-Turki and Al-Olayan, 2003; Sharawy and Alshammari, 2009; El-Ghanim ***et al***., 2010; and Llewwllyn ***et al***., 2011).

Poaceae followed by Asteraceae, Chenopodiaceae, Brassicaceae and Fabaceae were the most dominant families. Those families have been documented previously as the most common in the flora of Saudi Arabia (Migahid and Hammouda, 1978; Collenette, 1985; Mandaville, 1990; Abd El-Ghani and El-Sawaf, 2004). Also, the families Poaceae, Asteraceae, Fabaceae, Chenopodiaceae and Brassicaceae were well documented to comprise the main bulk of the wild plants in Ha'il region (Alshammari and Sharawy, 2010 and Llewwllyn ***et al.***, 2011).

The life form (LF), according to Raunkiaer's system of classification (Raunkiaer, 1934) showed that the most frequent life form class was Therophytes followed by Chaemophytes and Phanerophytes. This result confirms the concept of Cain (1950) and Deschenes (1969) how reported that factors such as overgrazing, dry climate and trampling tend to increase the percentage of Therophytes through the introduction and spread of weedy grasses and forbs. Such results agree also with the life form spectra in desert habitats in some other parts of Saudi Arabia as mentioned by (El-Demerdash ***et al***., 1994; Collenette, 1999; Al-Turki and Al-Olayan, 2003; Alshammari and Sharawy, 2010; El-Ghanim ***et al***., 2010; Alatar ***et al***., 2012; Daur, 2012; El-Ghazali and Al-Soqeer, 2013). Also, the low presence of Phanerophytes (5.15%) recorded in this study is in agreement with the findings of Al-Turki and Al-Olayan (2003), which showed that central and north Arabian Peninsula has very poor species of perennial shrubs and trees.

**Table 2:** List of the recorded weed species, their growth form and life form in alfalfa and wheat fields in Ha'il Region.

| No. | Family | Taxa | Growth Form | Life Form | Occurence Alfalfa Fields | Occurence Wheat Fields |
|---|---|---|---|---|---|---|
| 1 | Aizoaceae | *Aizoon canariensis* L. | H, Ann. | Th. | + | + |
| 2 | | *Mesembryanthemumn nodiflorum* L. | H, Ann. | Th. | + | - |
| 3 | Amaranthaceae | *Amaranthus albus* L. * | H, Ann. | Th. | + | - |
| 4 | | *Amaranthus graecizans* L. | H, Ann. | Th. | + | + |

| No. | Family | Taxa | Growth Form | Life Form | Occurence | |
|---|---|---|---|---|---|---|
| | | | | | Alfalfa Fields | Wheat Fields |
| 5 | | *Amaranthus lividus* L. | H, Ann. | Th. | + | - |
| 6 | Apiaceae | *Anisosciadium isosciadium* Bornm | H, Ann | Th. | + | - |
| 7 | Asphodelaceae | *Asphodellus fisulosus* L. | H, Ann. | Th. | + | - |
| 8 | Asteraceae | *Anvillea garcini* (Burn.f.) D. | S, Per. | Ph. | + | - |
| 9 | | *Atractylis cancellata* L. | H, Ann. | Th. | + | - |
| 10 | | *Calendula arvensis* L. | H, Ann. | Th. | + | - |
| 11 | | *Calendula tripterocarpa* Rupr. | H, Ann. | Th. | + | + |
| 12 | | *Conyza bonariensis* (L.) Cronquist | H, Ann. | Th. | + | - |
| 13 | | *Conyza canadensis* (L.) Cronquist * | H, Ann. | Th. | + | - |
| 14 | | *Conyza stricta* Willd. * | H, Ann. | Th. | + | + |
| 15 | | *Filago desertorum* Pomel | H, Ann. | Th. | + | - |
| 16 | | *Koelpinia linearis* Pall. | H, Ann. | Th. | + | - |
| 17 | | *Lactuca saligna* L. * | H, Ann. | Th. | + | - |
| 18 | | *Lactuca serriola* L. * | H, Ann. | Th. | + | + |
| 19 | | *Launaea resedifolia* Druce | H, Ann. | Th. | + | + |
| 20 | | *Rhanterium epapposum* Oliv. | S, Per. | Ph. | + | + |
| 21 | | *Senecio flavus* (Decne.) Sch.Bip. | H, Ann. | Th. | + | - |
| 22 | | *Sonchus oleraceus* L. | H, Ann. | Th. | + | + |
| 23 | | *Urospermum picroides* (L.) Scop. | H, Ann. | Th. | + | - |
| 24 | Boraginaceae | *Arnebia hispidissima* (Lehm.) DC. | H, Ann. | Th. | + | + |
| 25 | | *Heliotropium digynum* (Forssk.) Asch. Ex C. Christens. | H, Per. | Ch. | + | + |
| 26 | Brassicaceae | *Brassica tournefortii* Gouan | H, Ann. | Th. | + | - |
| 27 | | *Capsella bursa-pastoris* (L.) Medik. | H, Ann. | Th. | + | - |
| 28 | | *Eruca sativa* (L.) Mill. | H, Ann. | Th. | + | - |
| 29 | | *Farsetia aegyptia* Turra. | H, Per. | Ch. | + | - |
| 30 | | *Sisymbrium irio* L. | H, Ann. | Th. | + | + |
| 31 | | *Sisymbrium orientale* L. | H, Ann. | Th. | + | + |
| 32 | | *Zilla spinosa* (Turr.) Prantl. | S, Per. | Ph. | + | - |
| 33 | Caryophyllaceae | *Herniaria hirsuta* L. | H, Ann. | Th. | + | - |
| 34 | | *Paronychia arabica* DC. | H, Per. | Ch. | + | - |
| 35 | | *Spergularia diandra* (Guss.) Heldr. &Sart. | H, Ann. | Th. | + | - |
| 36 | Chenopodiaceae | *Anabasis setifera* Moq. | H, Per. | Ph. | + | - |
| 37 | | *Atriplex suberecta* Verdoorn * | H, Ann. | Th. | + | - |
| 38 | | *Beta vulgaris* L. | H, Ann. | Th. | + | - |
| 39 | | *Chenopodium album* L. Bosc. * | H, Ann. | Th. | + | + |
| 40 | | *Chenopodium ambrosioides* L. * | H, Ann. | Th. | + | - |
| 41 | | *Chenopodium glaucum* L. * | H, Ann. | Th. | + | - |
| 42 | | *Chenopodium murale* L. | H, Ann. | Th. | + | + |
| 43 | | *Salsola baryosma* (Schult.) Dandy | H, Per. | Ch. | + | - |
| 44 | | *Suaeda aegyptiaca* (Hasselq.) Zoh. | H, Per. | Ch. | + | + |
| 45 | Convolvulaceae | *Convolvulus arvensis* L. | H, Per. | Ch. | + | + |
| 46 | Cucurbitaceae | *Citrullus colocynthis* (L.) Schrad. | H, Per. | Th. | + | - |
| 47 | Cuscutaceae | *Cuscuta planiflora*Ten. | H, Ann. | P. | + | - |
| 48 | Euphorbiaceae | *Euphorbia retusa*(L.) Cav. | H, Ann. | Th. | + | - |
| 49 | | *Chrozophora tinctoria* (L.) Raf. | H, Per. | Ch. | + | - |
| 50 | Fabaceae | *Astragalus hamosus* L. | H, Ann. | Th. | + | + |
| 51 | | *Medicago laciniata* (L.) Mill. | H, Ann. | Th. | + | + |
| 52 | | *Melilotus indica* (L.) All. | H, Ann. | Th. | + | - |
| 53 | | *Trifolium tomentosum* L. | H, Ann. | Th. | + | - |
| 54 | | *Trigonella stellata* Forsssk. | H, Ann. | Th. | + | + |
| 55 | Fumariaceae | *Fumaria parviflora* Lam. | H, Ann. | Th. | + | - |
| 56 | Malvaceae | *Malva parviflora* L. | H, Ann. | Th. | + | + |
| 57 | Neuradaceae | *Neurada procumbens* L. | H, Ann. | Th. | + | - |

| No. | Family | Taxa | Growth Form | Life Form | Occurence | |
|---|---|---|---|---|---|---|
| | | | | | Alfalfa Fields | Wheat Fields |
| 58 | Orobanchaceae | *Cistanche violacea* (Dersf.) Beck. * | H, Per. | P. | + | - |
| 59 | | *Orobanche cernua* Loefl. | H, Ann. | P. | + | - |
| 60 | | *Orobanche ramose* L. | H, Ann. | P. | + | - |
| 61 | Plantaginaceae | *Plantago ovata* Phil. | H, Ann. | Th. | + | + |
| 62 | Poaceae | *Aleuropus lagopoides* (L.) Trin. Ex Thwaites * | H, Per. | Ch. | + | - |
| 63 | | *Cenchrus ciliaris* L. | H, Ann. | Th. | + | + |
| 64 | | *Chloris virgata* Swartz. * | H, Ann. | Th. | + | + |
| 65 | | *Cutandia dichotoma* (Forssk.) Trab. * | H, Ann. | Th. | - | - |
| 66 | | *Cynodon dactylon* (L.) Pers. | H, Per. | Hem. | + | - |
| 67 | | *Dactyloctenium scindicum* Boiss. * | H, Ann. | Th. | + | - |
| 68 | | *Dichanthium annulatum* (Forssk.) Stapf. * | H, Ann. | Th. | + | - |
| 69 | | *Digitaria sanguinalis (*L.) Scop. * | H, Ann. | Th. | + | + |
| 70 | | *Echinochloa colonum* (L.) Link. * | H, Ann. | Th. | + | - |
| 71 | | *Eleusine indica* (L.) Gaertn. * | H, Ann. | Th. | + | - |
| 72 | | *Eragrostis cilianensis* (All.) F.T. Hubb. | H, Ann. | Th. | + | + |
| 73 | | *Hordeum leporinum* Link. | H, Ann. | Th. | + | + |
| 74 | | *Lasiurus scindicus* Henr. * | H, Per. | Ch. | + | - |
| 75 | | *Lolium temulentum* L. * | H, Ann. | Th. | - | + |
| 76 | | *Lolium multiflorum* Lam. * | H, Ann. | Th. | + | + |
| 77 | | *Lolium rigidum* Gaudich. * | H, Ann. | Th. | + | + |
| 78 | | *Panicum repens* L. * | H, Per. | Hem. | + | + |
| 79 | | *Poa annua* L. * | H, Ann. | Th. | + | + |
| 80 | | *Polypogonm monspeliensis* (L.) Desf. | H, Ann. | Th. | + | + |
| 81 | | *Schismus barbatus* (L.) Thell. | H, Ann. | Th. | + | + |
| 82 | | *Setaria verticillata* (L.) P. Beauv. | H, Ann. | Th. | + | - |
| 83 | | *Stipa capensis* Thunb. | H, Ann. | Th. | + | - |
| 84 | Polygonaceae | *Emex spinosa* (L.) Campd. | H, Ann. | Ch. | + | - |
| 85 | | *Polygonum equisetiforme* Sm. | H, Ann. | Ch. | + | + |
| 86 | | *Rumex vesicarius* L. | H, Ann. | Th. | + | + |
| 87 | Portulacaceae | *Portulaca oleracea* L. | H, Ann. | Th. | + | - |
| 88 | Primulaceae | *Anagallis arvensis* L. | H, Ann. | Th. | + | + |
| 89 | Resedaceae | *Reseda arabica* Boiss. | H, Ann. | Th. | + | + |
| 90 | Solanaceae | *Solanum elaeagnifolium* Cav. * | H, Per. | Ch. | + | - |
| 91 | | *Solanum nigrum* L. | H, Per. | Ch. | + | + |
| 92 | | *Withania somnifera* (L.) Dun. | S, Per. | Ph. | + | - |
| 93 | Urticaceae | *Forsskaolea tenacissima* L. | H, Ann. | Ch. | + | - |
| 94 | Zygophyllaceae | *Fagonia glutinosa* Del. | H, Per. | Ch. | + | + |
| 95 | | *Tribulus terrestris* L. | H, Ann. | Th. | + | - |
| 96 | | *Zygophyllum simplex* L. | H, Ann. | Th. | + | - |
| 97 | | *Zygophyllum coccineum* L. | H, Per. | Ch. | + | - |

**Note: Ann.,** Annual; **Per.,** Perennial; **H,** Herb; **S,** Shrub; **Th,** Therophytes; **Ph,** Phanerophytes; **Ch,** Chaemophytes; **Hem,** Hemicryptophytes; **P,** Parasites.
***,** species recorded for first time in Ha'il region.

Parasitic species such as *Cuscuta planiflora*, *Cistanche violacea*, *Orobanche cernua* and *Orobanche ramose* were found to be the major parasitic weeds. Parasitic weeds are well known to infest agricultural crops and cause growth damage and yield failure. These parasitic weeds have the ability of producing a large number of seeds accompanied with long seed viability and ability to widely spread by wind such as Cistanche and Orobanche, and hence pose more complications for the control methods (Qasem, 2010). Unfortunately, the current data of parasitic weeds would damage two of the most important crops in Ha'il region (Alfalfa and Wheat), and accordingly special control programs and management activities should be undertaken promptly to hinder their spreading.

The present study showed that six species (*Aizoon canariensis, Mesembryanthemum nodiflorum, Suaeda fruticosa, Portulaca oleracea, Zygophyllum simplex* and *Zygophyllum coccineum*) were encountered as succulent weeds affecting drying the fodder crops in Ha'il region. These weeds are water retaining plants as they store water in various parts, such as leaves and stems to adapt itself against the long dry season. Succulent weeds are not only adversely affecting the yield of fodder crops, but also, when harvested with these fodder crops, it slows their process of drying and may leads to reducing their quality. Moreover, Sharawy and Alshammari (2009) reported these species to be poisonous plants for grazing animals.

Few species like *Amaranthus albus, Paronychia arabica, Chenopodium album, Chrozophora tinctoria, Cutandia dichotoma, Dichanthium annulatum, Setaria verticillata, Emex spinosa* and *Solanum elaeagni*folium are weeds which documented as rare species in this study and found to occur only on the margins. Therefore, field margins deserve special attention as biodiversity refuges in areas of intensive agriculture.

## 5. CONCLUSIONS

In conclusion, ninety seven weed species belonging to eighty one genera from twenty seven families were recorded in the current research. The floristic analysis showed that the majority of those weeds were annual herbs, while only four species lies in the shrub category namely, (*Anvillea garcini*, *Rhanterium epapposum*, *Zilla spinosa* and *Withania somnifera*).

Also, twenty six species were recorded for the first time in Ha'il region (Table 2). According to this result it is believed that some weeds from nearby regions like Qassim region may invade agricultural farms in Ha'il and become part of its weed flora. Out of these twenty six new record species; about sixteen species are belonging to the family Poaceae. The dominance of the Poaceae family in the current study has been recorded also all over Saudi Arabia which reflects the critical infestation of this family and therefore the necessity of applying more strict methods of weed control.

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# Glycine Betaine Boosts Growth, Chlorophyll a Fluorescence, and Alleviated Drought-induced Damage in Eggplant (*Solanum melongena* L.)

*Saad M. Howladar and Fatima Omari Al-Zahrani*[1]

***ABSTRACT*:** Osmoprotectants such as glycine betaine (GB) widely accumulate in plants, and mediate various physiological and biochemical processes. In the current study, we investigated the effect on foliar application of GB on enhancing drought stress tolerance in eggplant (*Solanum melongena* L.) during early vegetative growth stages. GB was exogenously applied at three different concentrations (0, 25, and 50 mM) under three levels of irrigation (FI, Ir-80, and Ir-60, i.e., 100%, 80%, and 60% of the soil water-holding capacity [SWHC], respectively).

The results revealed that the deficit irrigation (DI) at Ir-80 and Ir-60) significantly decreased all growth characteristics (i.e., number of leaves per plant, shoot length, stem diameter, leaf area per plant, and shoot fresh weight and dry weight). The physiological attributes were also affected (i.e., chlorophyll *a* fluorescence; Fv/Fm, Fv/F0, and performance index (PI), SPAD chlorophyll, relative water content [RWC], and membrane stability index [MSI]). However, foliar application of GB alleviated DI stress effects in eggplant plants by improving photosynthetic efficiency (evaluated by chlorophyll *a* fluorescence) and enhanced RWC and MSI in the tested eggplants. This in turn reflected in higher plant growth characteristics and improved plant water status under DI stress. Therefore, foliar application of GB may have future commercial applications as a potential osmolyte for improving plant growth under DI of up to 40% of the SWHC.

**Keywords:** Glycine betaine, drought stress, chlorophyll *a* fluorescence, dehydration tolerance

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## 1. INTRODUCTION

Eggplant (*Solanum melongena* L.) is one of the most important crops grown worldwide and in Saudi Arabia, which has a dry climate as it lies in an arid region (Zabin and Howladar, 2015) In such regions, lack of fresh water resources is the major factor restricting agricultural production. Better awareness of water efficiency is considered a successful management strategy and a sustainable agricultural practice in water-limited environments (Howell, 2001; Bacon, 2004). Irrigation using water that is less than the optimum water requirement of the crop is called deficit irrigation (DI). It is a common sustainable practice worldwide (Pereira ***et al***., 2002), especially in regions characterized by low water resources. There are two main potential benefits of DI: increased water use efficiency and decreased irrigation costs. DI may be performed either by decreased frequency of irrigation or decreased of irrigation water amount (Patane ***et al***., 2011; Igbadun ***et al***., 2012). DI affects growth and yield of many vegetables and field crops (Abd El-Mageed ***et al***., 2016a, 2016b; Merwad ***et al***., 2018). DI increases water productivity without severe reduction in crop yield (Geerts and Raes, 2009; Semida ***et al***., 2017).

On the other hand, eggplant is a plant with a high water requirement during its growth and development stages; therefore, it is considered drought-sensitive (Fu ***et al.***, 2013). In addition, marketable fruits and yield components of hydroponically cultivated zucchini were considerably affected by irrigation system (Rouphael and Colla, 2005). DI affected the water productivity and water use efficiency of squash (Abd El-Mageed and Semida, 2015a). Different effects of DI are crop-specific; therefore, to accommodate a given crop to a specific location, it is crucial to evaluate the effect of different DI strategies through multi-year open-field experiments before concluding the most suitable irrigation scheduling method (Abd El-Mageed and Semida, 2015b).

Glycine betaine (GB) is an amino acid derivative that accumulates in a wide number of plant species in response to abiotic stresses, including drought (Gorham, 1995). Several reports have elucidated that exogenous GB application improved the growth and yield of wheat and rice plants by regulating some key physiological and molecular attributes, thereby increasing drought tolerance in these plants (Weibing and Rajashekar, 1999; Tahir ***et al***., 2009; Hadiarto and Tran, 2011; Gao ***et al***., 2012; Cha-um ***et al***., 2013).

Therefore, the main objective of this study was to assess the effect of foliar application of GB on the growth and physiological attributes of eggplant grown at 20 or 40% DI in comparison with eggplant grown with full irrigation. The results could be useful in developing additional strategies for the sustainable management of eggplant production under limited irrigation.

## 2. MATERIALS AND METHODS

From March 2017 to May 2017, a pot experiment with three replicates was conducted during the period of March–May, 2017 in a greenhouse at Albaha University, Alaqiq (latitude 20° 17′ 41″N, longitude 41° 38′ 35″E, 1651.88 m above sea level), Albaha, Saudi Arabia. The climate of the study region is semiarid (Zabin and Howladar, 2015) and is described as having a mean annual temperature ranging from 17.8–29.9°C. The average annual rainfall is reported to be about 62.45 mm, and the relative humidity ranges from 15–87%. The mean wind speed is around 6 kts/deg (PMEP, 2017).

At the fourth leaf stage, eggplant (*Solanum melongena* L.) seedlings were transplanted into plastic pots (25 cm diameter, 25 cm depth) containing 8 kg sandy loam soil. Starting at 10 days after transplanting (DAT), all plants per treatment (n = 30) were sprayed with tap water (0 mM GB) or 25 and 50 mM of GB two times to run-off, at 10-day intervals. The sprays received drops of the surfactant Tween-20 drops to ensure complete penetration of the GB solution into the leaves. Each GB treatment was carried out under three levels of irrigation (full irrigation [FI], Ir-80, and Ir-60, with 100%, 80%, and 60% of soil water-holding capacity [SWHC], respectively). Plants (n = 30) from all the treatment groups received FI until the start of the treatment applications (10 DAT), then all DI treatments were applied with the first GB spray. The electrical conductivity (EC) and pH values and the contents of cations and anions in the soil used for the experiments are shown in Table 1.

**Table 1.** Physico-chemical characteristics of a sandy loam soil prior to the experiments in two seasons

| Bulk density ($g \cdot cm^{-3}$) | CEC ($cmol^+/kg$) | pH | EC ($dS \cdot m^{-1}$) | OC* | N | P | K | Ca | Fe | Mn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ($g \cdot kg^{-1}$) | | ($mg \cdot kg^{-1}$) | | | | | |
| 1.29 | 7.9 | 7.7 | 2.1 | 8.9 | 0.8 | 15 | 70 | 85 | 6.2 | 4.0 | 2.1 |

The SWHC in each pot was 36% (w/v) soil:water, which was measured by saturating the soil in each pot with water and weighing it after it had drained for 48 h. The soil water contents were maintained at approximately 100% (w/v) of the SWHC for the control treatment. The soil moisture level was controlled by weighing each pot, and water loss was supplemented daily according to the irrigation treatments.

According to the recommended doses of agricultural practices, nitrogen (N) as ammonium sulfate (20.5% N) at 2.0 g per pot, phosphorous (P) as calcium superphosphate (15.5% $P_2O_5$) at 1.2 g per pot, and potassium (K) as potassium sulfate (48% $K_2O$) at 1.0 g per pot were added to each pot before planting. An additional N dose of 1.2 g ammonium sulfate per pot (20.5% N) was added at 26 DAT. The experiment was arranged in a factorial layout based on RCB design with 15 replicates (pots) per experimental treatment. The experiments were terminated at 42 DAT.

After six weeks of transplanting, five destructive plant samples were randomly chosen from each experimental treatment to determine plant growth, dehydration tolerance, and photosynthetic efficiency.

## 2.1 Measurements

To measure the growth characteristics of the eggplant plants, five destructive plant samples were randomly chosen from each experimental treatment at the end of the experimental period (42 DAT) to determine plant growth, dehydration tolerance, and photosynthetic efficiency.

The number of leaves per plant was counted and the leaf area per plant ($m^2$) was assessed using a digital planimeter (Delta-T DIAS image analysis system, Cambridge, UK). Shoot length and stem diameter were measured using the Vernier Caliper (Mahr UK PLC). Shoot fresh weight was assessed, and shoot dry weight (g) was measured after oven-drying the shoots at 70 °C for 48 h.

On a successive period in 2 different (sunny) days, the photosynthetic efficiency (chlorophyll fluorescence) was evaluated with a Handy PEA fluorometer (Hansatech Portable Instruments Ltd., Kings Lynn, UK). A corresponding fourth leaf was evaluated on each randomly chosen plant. The maximum PS II $Fv/Fm$ quantum yield was calculated using the Maxwell and Johnson (2000) formulae; $Fv/Fm = (Fm - F0)/Fm$. The photosynthesis performance index was calculated based on equal absorption (PIABS) (Clark ***et al.***, 2000). The SPAD chlorophyll was measured in the apical third and fourth leaves using a chlorophyll meter (SPAD-502, Minolta, Japan).

Tissue relative water content (RWC) was measured according to the method described by Hayat ***et al.*** (2007) using fully-expanded leaf discs. First, the weights of the discs were recorded (fresh mass; FM) and immediately floated on double-distilled water in petri dishes for 24 h, in the dark, to saturate the discs with water. Any adhering water was gently removed by drying and the turgid mass (TM) was recorded. Dry mass (DM) was taken after drying the discs at 70°C until constant weight was achieved. The RWC was then calculated using the following formula:

$$\mathrm{RWC}(\%) = \left[\frac{(\mathrm{FM} - \mathrm{DM})}{(\mathrm{TM} - \mathrm{DM})}\right] \times 100$$

The membrane stability index of plant tissues (MSI) was determined based on the method of Rady (2011) using two comparable samples of fully-expanded leaf tissues. One sample was transferred into a test tube containing double-distilled water. This test tube was then heated at 40°C in a water bath for 30 min, and the electrical conductivity (EC1) of the solution was registered utilizing a conductivity bridge. The other sample was boiled at 100°C for 10 min, the conductivity was recorded (EC2), and the MSI was calculated using the following formula:

$$\mathrm{MSI}(\%) = \left[1 - \left(\frac{\mathrm{EC1}}{\mathrm{EC2}}\right)\right] \times 100$$

### 2.2 Statistical analysis

The collected data were subjected to analysis of variance using Genstat statistical package (VSN International Ltd, Oxford, UK). Mean multiple comparisons were conducted by the least significant difference test at a probability value of 0.05.

## 3. RESULTS

Eggplant transplants displayed a significant reduction in growth characteristic and physiological attributes in response to the increased levels of DI treatments (Ir-80 and Ir-60). The DI significantly decreased growth pertaining parameters (i.e., number of leaves, shoot length, stem diameter, shoot fresh weight (FW), shoot dry weight (DW), and leaf area; Tables 2a, b and 3a, b) and physiological attributes (i.e., photosynthetic efficiency evaluated by chlorophyll *a* fluorescence; *Fv/Fm*, *Fv/F0* ratios and PI [Figure 1 and Table 4], SPAD chlorophyll, RWC, and MSI [Tables 5a, b]).

**Table 2a.** Effect of glycine betaine (GB) foliar application on some growth characteristics i.e., leaves number, shoot length, and stem diameter of eggplant (*Solanum melongena* L.) transplants grown under deficit irrigation regimes

| Items | Mean ± SE | | |
|---|---|---|---|
| | Leaf number | Shoot length (cm) | Stem diameter (mm) |
| **GB** | | | |
| GB (0 mM) | 18.50 ± 0.96 [c#] | 18.42 ± 0.79 [c] | 5.74 ± 0.10 [b] |
| GB (25 mM) | 23.39 ± 1.26 [b] | 24.80 ± 0.65 [b] | 6.06 ± 0.16 [b] |
| GB (50 mM) | 27.83 ± 1.61 [a] | 27.43 ± 0.67 [a] | 6.46 ± 0.19 [a] |

| Items | Mean ± SE | | |
|---|---|---|---|
| | Leaf number | Shoot length (cm) | Stem diameter (mm) |
| **Crop evapotranspiration (ETc)** | | | |
| FI (control) | 27.17 ± 1.49 [a] | 24.37 ± 0.71 [a] | 6.37 ± 0.18 [a] |
| Ir-80 | 23.94 ± 1.39 [b] | 23.85 ± 1.33 [ab] | 6.32 ± 0.14 [a] |
| Ir-60 | 18.61 ± 1.14 [c] | 22.44 ± 1.27 [b] | 5.57 ± 0.11 [b] |

[#]Values in each column are the means ± standard error of (n = 6). Mean values followed by a different lowercase letter are significantly different by Duncan's multiple range test at P ≤ 0.05.

FI = irrigation with 100% of soil water-holding capacity (SWHC), Ir-80 = irrigation with 80% of SWHC, and Ir-60 = irrigation with 60% of SWHC.

**Table 2b.** Mean square, *F* value, and probability for leaf number (LN), shoot length (SL), and stem diameter (SD).

| Items | d.f. | Mean square | | | *F* value and probability | | |
|---|---|---|---|---|---|---|---|
| | | LN | SL | SD | LN | SL | SD |
| GB | 2 | 392.30 | 386.33 | 2.32 | 21.60* | 52.53* | 8.58* |
| ETc | 2 | 336.07 | 17.90 | 3.62 | 18.50* | 2.43[ns] | 13.38* |
| GB X ETc | 4 | 14.66 | 31.89 | 0.60 | 0.81[ns] | 4.34* | 2.22[ns] |
| Exp. Error | 40 | 18.17 | 7.35 | 0.27 | | | |

[ns] = non-significant, * Significant at the $P \leq 0.05$ level.

**Table 3a.** Effect of GB foliar application on some growth characteristics i.e., shoot fresh weight (FW), shoot dry weight (DW), and leaf area of eggplant (*Solanum melongena* L.) transplants grown under deficit irrigation regimes

| Items | Mean ± SE | | |
|---|---|---|---|
| | Shoot FW/plant (g) | Shoot DW/plant (g) | Leaf area/plant ($dm^2$) |
| **GB** | | | |
| GB (0 mM) | 26.34 ± 1.37[b#] | 2.60 ± 0.15[b] | 1.17 ± 0.06[c] |
| GB (25 mM) | 30.44 ± 1.63[ab] | 2.94 ± 0.15[ab] | 1.41 ± 0.07[b] |
| GB (50 mM) | 31.11 ± 1.84[a] | 3.27 ± 0.19[a] | 1.61 ± 0.09[a] |
| **Crop evapotranspiration (ETc)** | | | |
| FI (control) | 32.24 ± 1.57[a] | 3.49 ± 0.18[a] | 1.60 ± 0.08[a] |
| Ir-80 | 31.60 ± 1.53[a] | 2.88 ± 0.11[b] | 1.47 ± 0.07[a] |
| Ir-60 | 24.06 ± 1.21[b] | 2.44 ± 0.14[c] | 1.13 ± 0.05[b] |

#Values in each column are the means ± standard error of (n = 6). Mean values followed by a different lowercase letter are significantly different by Duncan's multiple range test at P ≤ 0.05.

FI = irrigation with 100% of SWHC, Ir-80 = irrigation with 80% of SWHC, and Ir-60 = irrigation with 60% of SWHC.

**Table 3b.** Mean square, *F* value, and probability for shoot FW, shoot DW, and leaf area.

| Items | d.f. | Mean square | | | *F* value and probability | | |
|---|---|---|---|---|---|---|---|
| | | Shoot FW | Shoot DW | Leaf area | Shoot FW | Shoot DW | Leaf area |
| GB | 2 | 119.86 | 2.04 | 0.84 | 3.00* | 6.44* | 12.00* |
| ETc | 2 | 372.39 | 5.01 | 1.06 | 9.32[ns] | 15.78* | 15.10* |
| GB X ETc | 4 | 14.27 | 0.33 | 0.08 | 0.36[ns] | 1.06[ns] | 1.14[ns] |
| Exp. error | 40 | 39.98 | 0.31 | 0.07 | | | |

[ns] = non-significant, * Significant at the $P \leq 0.05$ level.

**Table 4.** Mean square, *F* value, and probability for chlorophyll *a* fluorescence i.e., $Fv/Fm$, $Fv / F_0$, and PI.

| Items | d.f. | Mean square | | | *F* value and probability | | |
|---|---|---|---|---|---|---|---|
| | | $Fv/Fm$ | $Fv / F_0$ | PI | $Fv/Fm$ | $Fv / F_0$ | PI |
| GB | 2 | 0.002 | 1.00 | 22.52 | $2.21^{ns}$ | $2.77^{ns}$ | $3.09^{ns}$ |
| ETc | 2 | 0.005 | 2.63 | 10.50 | $7.66^{*}$ | $7.27^{*}$ | $1.44^{ns}$ |
| GB X ETc | 4 | 0.001 | 0.92 | 13.72 | $1.91^{ns}$ | $2.54^{ns}$ | $1.88^{ns}$ |
| Exp. error | 40 | 0.001 | 0.36 | 7.28 | | | |

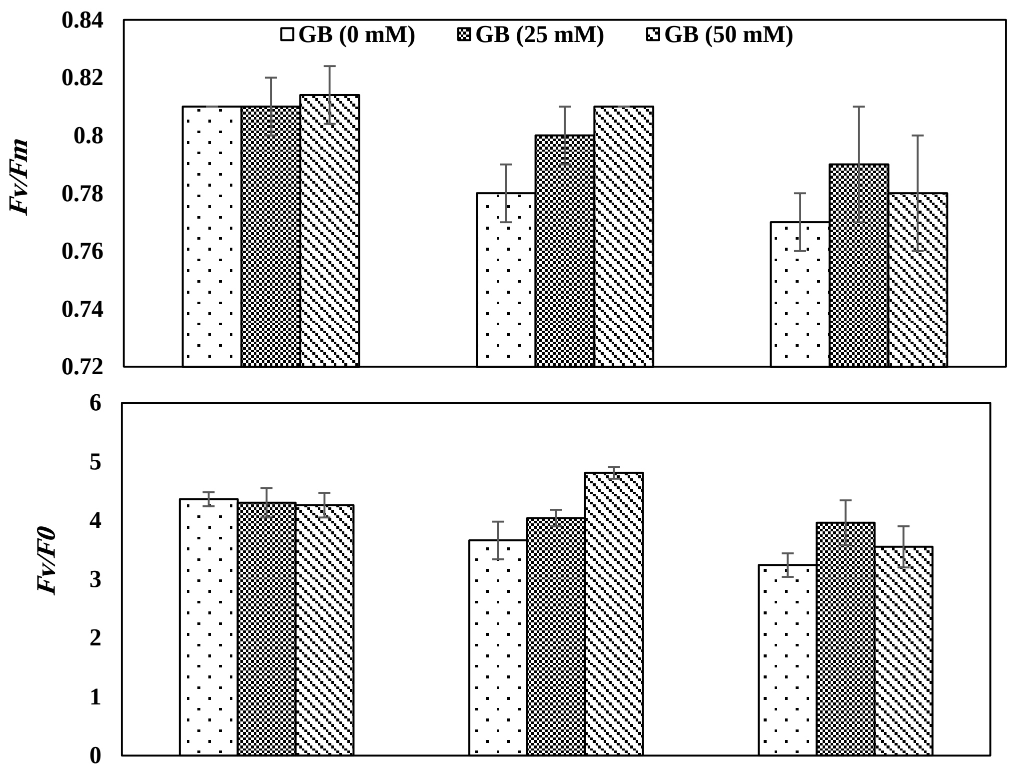
$^{ns}$ = non-significant, $^{*}$ Significant at the $P \leq 0.05$ level.

**Table 5a.** Effect of GB foliar application on relative chlorophyll content (SPAD value), relative water content (RWC%), and membrane stability index (MSI%) of eggplant (*Solanum melongena* L.) transplants grown under deficit irrigation regimes

| Items | Mean ± SE | | |
|---|---|---|---|
| | SPAD | RWC% | MSI% |
| **GB** | | | |
| GB (0 mM) | $42.02 \pm 1.67^{b\,\#}$ | $70.09 \pm 1.57^{b}$ | $30.87 \pm 1.31^{b}$ |
| GB (25 mM) | $52.28 \pm 1.61^{a}$ | $74.14 \pm 1.47^{a}$ | $36.09 \pm 1.60^{a}$ |
| GB (50 mM) | $55.01 \pm 0.90^{a}$ | $75.29 \pm 1.57^{a}$ | $36.40 \pm 0.54^{a}$ |
| **Crop evapotranspiration (ETc)** | | | |
| FI (control) | $49.14 \pm 1.83^{ab}$ | $79.32 \pm 0.70^{a}$ | $36.01 \pm 1.43^{a}$ |
| Ir-80 | $52.29 \pm 1.75^{a}$ | $72.94 \pm 1.08^{b}$ | $34.22 \pm 1.19^{ab}$ |
| Ir-60 | $47.87 \pm 2.10^{b}$ | $71.06 \pm 0.94^{b}$ | $32.13 \pm 1.12^{b}$ |

$^{\#}$Values in each column are the means ± standard error of (n = 6). Mean values followed by a different lowercase letter are significantly different by Duncan's multiple range test at $P \leq 0.05$.

FI = irrigation with 100% of SWHC, Ir-80 = irrigation with 80% of SWHC, and Ir-60 = irrigation with 60% of SWHC.



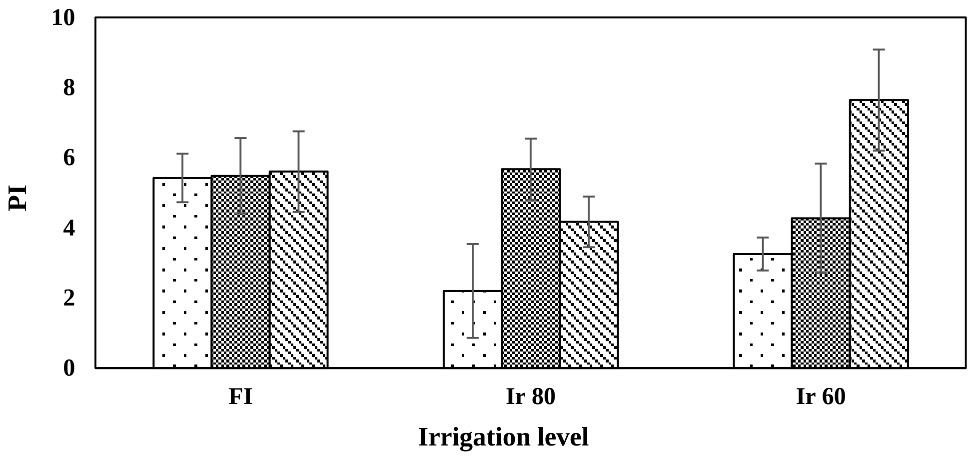



**Fig. 1:** Effect of glycine betaine (GB) foliar application on chlorophyll *a* fluorescence i.e., *Fv/Fm, Fv / $F_0$*, and PI of eggplant (*Solanum melongena* L.) transplants grown under deficit irrigation regimes.

**Table 5b.** Mean square, *F* value, and probability for relative chlorophyll content (SPAD value), RWC%, and MSI%.

| Items | d.f. | Mean square | | | *F* value and probability | | |
|---|---|---|---|---|---|---|---|
| | | SPAD | RWC% | MSI% | SPAD | RWC% | MSI% |
| GB | 2 | 844.08 | 5.01 | 40.66 | 22.64* | 0.50ns | 3.52* |
| ETc | 2 | 93.28 | 168.39 | 34.03 | 2.50ns | 16.66* | 2.94ns |
| GB X ETc | 4 | 36.68 | 1.56 | 17.85 | 0.98ns | 0.15ns | 1.54ns |
| Exp. error | 40 | 37.28 | 10.11 | 11.57 | | | |

ns = non-significant, * Significant at the $P \leq 0.05$ level.

However, GB application limited the negative effects of DI on the above tested parameters and significantly improved them compared to the controls. Foliar application of 50 mM GB was better than that of 25 mM GB. For example, following foliar application of 50 mM GB, the shoot FW, shoot DW, and leaf area of eggplant were 31.11 ± 1.84, 3.27 ± 0.19, and 1.61 ± 0.09, respectively, while the corresponding values following 25 mM GB treatment were 30.44 ± 1.63, 2.94 ± 0.15, and 1.41 ± 0.07 respectively.

This better GB treatment increased the number of leaves per plant by 50.4%, shoot length by 48.9%, stem diameter by 12.5%, leaf area per plant by 37.6%, shoot FW by 18.1%, shoot DW by 25.8%, Fv/Fm by 6.3%, Fv/F0 by 12.0%, PI by 60.2%, SPAD chlorophyll by 30.9%, RWC by 7.4%, and MSI by 17.9% compared to the untreated plant.

## 4. DISCUSSION

One of the key results of this study is the positive response of eggplant (*Solanum melongena* L.) transplants to foliar application of GB under drought stress by enhancing dehydration tolerance expressed by RWC, membrane stability index (MSI), and chlorophyll content (SPAD value).

The results of this study indicate that increasing the DI significantly reduced ($P \leq 0.05$) all growth parameters of eggplant. This growth reduction under DI could be attributed to the role of water in increasing the uptake of mineral elements from soil and translocation of photosynthetic assimilates, reflecting increases in the number of leaves and leaf area per plant, as well as shoot FWs and DWs per plant (Ragab ***et al***., 2015). On the other hand, drought stress caused by DI leads to various physio-biochemical adverse effects in plants (Farooq ***et al***., 2009; Bhardwaj and Yadav, 2012; Zhang and Huang, 2013). However, decrease in shoot fresh and dry biomass, shoot length, and plant leaf area have been shown to accompanied with DI stress (Tahir ***et al***., 2009; Mutava ***et al***., 2015), especially in plants grown in sandy soil (Ragab ***et al***., 2015). However, foliar application of GB was found to mitigate all eggplant growth parameters and treatment with 50 mM GB yielded higher significant values. These results are in line with the results reported in other works (Abbas ***et al***., 2010; Ragab ***et al***., 2015), in which foliar application of GB improved all growth characteristics of two eggplant cultivars. Such enhancements could be attributed to the fact that GB has been shown to improve the photosynthetic rate and stomatal conductance. GB penetrates the leaves of the plant directly after it is applied and readily translocates to the roots, meristems, and expanding leaves (Makela ***et al***., 1996). Therefore, developing and expanding plant organs are primarily protected from stress, improving plant growth. In addition, once GB is translocated to plant organs, it acts as an osmoprotectant in plant cells (McCue and Hanson, 1990).

With regard to photosynthetic efficiency, chlorophyll fluorescence is widely used as a stress screening indicator in a wide number of plants to determine injury or tolerance to various environmental stresses (Walker ***et al***., 1990; Weibing and Rajashekar, 1999). Commonly, the rate and yield of variable chlorophyll fluorescence decreased due to stress conditions (Weibing and Rajashekar, 1999). Further, DI stress decreases the photosynthetic rate in plants mainly due to decreased stomatal conductance as a result of increased abscisic acid content in plant leaves (Mutava ***et al***., 2015). The deleterious effect of DI on chlorophyll fluorescence was reduced by GB application. Also, it has been mentioned that the adverse effects of DI on $CO_2$ uptake and chlorophyll fluorescence in plants were fully or partially prevented by GB application (Weibing and Rajashekar, 1999; Ragab ***et al***., 2015). GB can improve the thermal stability and electron transport in photosystem II (Wiliams ***et al***., 1992). Similarly, GB protects the oxygen evolution in photosystem II against stress in spinach chloroplasts (Papageorgiou ***et al***., 1991).

DI stress treatments, especially Ir-60, significantly decreased the leaf RWC and MSI. These results are in line with results reported in other studies, which refer to the use of DI strategy as a very important approach to increase crop water use efficiency (WUE) (Kirda, 2002). Moreover, the adoption of DI strategies at 60% of the SWHC could be suggested in open-field eggplant for increasing the WUE and maximizing plant growth. Plants treated with GB under DI stress conditions showed a slower decrease in leaf water potential, thus developing wilting symptoms much later than untreated plants. However, GB-treated plants showed better ability to recover from wilting than untreated plants (Weibing and Rajashekar, 1999; Ragab ***et al***., 2015). This is because GB is an osmoprotectant, and it enables plants to maintain adequate amounts of water in tissue for healthy physiological-biochemical processes that can be positively reflected in the healthy growth of eggplant plants under DI stress. This phenomenon leads to saving up to 40% of irrigation water, which may be used in other important activities for human life.

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# Seed Germination and Seedling Growth of *Nigella Sativa* L. A High Value Medical Plant

*Khalil Mseddi* [1]

**ABSTRACT:**This work aims to study the germination conditions and the seedling growth of *Nigella sativa L.* This plant is renowned for its medicinal purposes used for centuries in Asia, Middle East and in Africa.

The germination requirements of *the* black cumin were studied under control conditions in the laboratory. The treatments included four light levels (0:24); (6:18); (12:12), and (24:0) hours of light: dark period. Seven salinity concentrations (0, 2, 4, 6, 8, 10 and 12 g/l NaCl), as well as seven temperature regimes (5°, 10°, 17°, 15°, 20°, 25° and 30° C), using a completely randomized block design.were tested in the present work.

This work shows that the germination of the black cumin was very sensitive to temperature with an optimum of 20°C. Germination stops below 10°C and above 25°C. The progressive increase of salinity until 8g/l has no significant effect on the germination ($p$<0.001). A significant inhibition of germination was obvious only after 10 g/l ($p$<0.001). The absence of light shows the best rate of germination that decreased when light period increases. Seedling monitoring shows that germination was achieved after 6 days, whereas the beginning of flowering was observed after 50 days from germination.

**Keywords:** *nigella sativa*, seed germination, seedling, salinity, light, temperature.

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## 1. INTRODUCTION

*Nigella sativa* Linn., family *Ranunculaceae*, is an annual flowering plant that is grown and cultivated in North Hijaz (Fig. 1), representing the western part of Saudi Arabia (Migahid 1987). Black cumin is widely cultivated throughout South Europe, Syria, Egypt, Saudi Arabia, Iran, Pakistan, India and Turkey (Riaz ***et al***. 1996, Özlem and Süleyman 2004).

Black cumin (*Nigella sativa* L.) is used frequently in traditional and industrial pharmacology (D'Antuno ***et al***. 2002). It is announced that intact black cumin seeds or their extracts contain anti-diabetic, antihistaminic, antihypertensive, anti-inflammatory, anti-microbial, antitumour, galactagogue and insect repellent effects (Riaz ***et al***. 1996, Siddiqui and Sharma 1996, Worthen ***et al***. 1998).

In Saudi Arabia, this species was found in, its habitats, in low density. People consider it like a sensitive species that can exist in very restricted regions. One of the fundamental factors that limits the dispersion of this species is its difficulty to germinate.

The environmental factors such as temperature, salinity, light, and soil moisture simultaneously influence the germination process (Ungar 1995, El-Keblawy and Al-Rawai 2005). The establishment of plants in arid regions is often limited by the temperature even though the conditions of humidity are favorable (Mseddi ***et al***. 2002, Visser ***et al***. 2008). Knowledge of temperature effects on germination may be useful to evaluate the germination characteristics or the establishment potential among range species (Mseddi ***et al***. 2003, Mnif ***et al***. 2005, Kharrat ***et al***. 2011). Tolerance to salinity during germination is critical for the establishment of plants growing in saline soil of arid regions (Ungar 1995).

This work, which was conducted in the laboratory of Botany and Plant Biology at the college of Sciences in Hail, aims to study the effects of temperature, salinity and light on the germination of *Nigella sativa*. After germination, the second part of this study was reserved for the monitoring of seedling growth up to the flowering stage of this plant species.

## 2. MATERIALS AND METHODS

The fruits (capsules) of *Nigella sativa* used in this experiment were harvested in 2010 from its natural populations within the areas of Kassim and the region of El Hijaz in Saudi Arabia (Fig. 1). The seeds were removed from follicles, air dried and stored in paper bags at room temperature (25-30˚C) and capsules. After weighting, the seeds are ready to experiments.

**Fig. 1.** Distribution map of *Nigella sativa* in Saudi Arabia

Only mature and intact seeds were used in the experiment. By the use of optic lens damaged and very small seeds were eliminated. Then seeds were divided into

groups each with 100 seeds. Every group was photographed and weighted, and then the average of 1000 seeds weight was calculated.
Germination trials were conducted in 9-cm sterile Petri dishes lined with two Whatman No. 1 filter papers and moistened with sterile distilled water to ensure adequate moisture for the seeds. To avoid fungus attack, seeds were surface sterilized in 0.1% mercuric chloride solution for 1 min, subsequently washed with distilled water and air-dried before being used in the germination experiments. Treatments were arranged in a factorial experiment (randomized complete block) with three replicates of 50 seeds each. Seed treatments included, 0/24 (continuous darkness), 8/16 and 16/8 h light/dark photoperiod.

The effect of temperature was determined by placing the Petri dishes in a germination chamber (incubator) for 20 days at constant temperatures of 5° C, 10° C, 15° C, 17° C, 20° C, 25° C and 30° C.
Seven salinity concentrations (0 g/l, 2 g/l, 4 g/l, 6 g/l, 8 g/l, 10 g/l and 12 g/l NaCl) were used based on a preliminary test for salt tolerance of the species.

For all attempts, the seeds were irrigated, counted and examined daily and considered germinated when the radicle was visible. At the end of the trials, data were subjected to analysis of variance procedures and mean separation using SPSS statistical packages.

To follow seedling phenology, small seedlings were transferred into growth tanks. Tanks were placed in a field with controlled conditions (temperature and light). To eliminate the competition, seedlings were separated by a distance of 5 cm.

## 3. RESULTS

*Nigella sativa* seeds were black, trigonal-shaped and have a small and short size (between 1-2 mm long). The average of the weight of 1000 seeds was 3.12±0.01 g.

In distilled water (0 g/l of salt) and continuous darkness, seeds of *Nigella sativa* were able to germinate at temperatures between 15° C and 25° C and the optimal temperature corresponds to 20 °C with percentage of germination of 72.4 %. At 10˚ C and 25˚ C, rates of germination were very low with respectively only 3.5 % and 4.5%. At 5˚ C and 30˚ C no germination were observed (Table 1).

**Table 1.** Percentage of germination seeds (rate of germination, %) of *Nigella sativa* at different experimental conditions of temperature and salinity. At the temperature 5˚C and 30˚C, as so as in salt concentration 12 g/l, no germination were recorded.

| NaCl (g/l) | Rate of germination (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5˚C | 10˚C | 15˚C | 17˚C | 20˚C | 25˚C | 30˚C |
| 0 | 0 | 3.5 ± 1.5 | 25 ± 3 | 63.5 ± 3.5 | 72.4 ± 4.5 | 4.5 ± 0 | 0 |
| 2 | 0 | 2.5 ± 1.5 | 21 ± 3.5 | 53.4 ± 1.6 | 64.5 ± 5.5 | 2.1 ± 1.5 | 0 |
| 4 | 0 | 2.5 ± 1.5 | 20.5 ± 4.5 | 42 ± 3.5 | 66.2 ± 3.8 | 2.1 ± 1.5 | 0 |
| 6 | 0 | 2.5 ± 1.5 | 15.5 ± 3.5 | 51.0 ± 4.0 | 63.5 ± 4.5 | 2.1 ± 1.5 | 0 |
| 8 | 0 | 0 ± 0 | 2.5 ± 1.5 | 11.5 ± 1.5 | 39.5 ± 5.5 | 0 ± 0 | 0 |
| 10 | 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 4.2 ± 2.8 | 0 ± 0 | 0 |
| 12 | 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0 |
| Salt effect | | | F = 49.213 | | $p < .001$ | | |
| T˚ effect | | | F = 429.461 | | $p < .001$ | | |
| Salt*T˚ | | | F interaction = 12.554 | | $p < .001$ | | |

At this optimal temperature (20˚C), the incubation time (or number of days before germination) was estimated at three days. However, the estimated delay of full germination was about seven days starting from the beginning of the experiment.

Temperature, salinity and their interaction significantly ($p$<0.0001) affected the final percentage of germination of *Nigella sativa* (Table 1). Seed germination was the highest in distilled water and germination percentages decreased slowly with the increase in salinity from 72.4% in distilled water to 63.5% in salt concentration of 6 g/l (Table 1). In all experimental temperature, differences were not significantly at the salt concentrations ranging from 2 to 6 g/l. Germination start to be affected only at 8 g/l of NaCl with 39.5 % then decrease to 4.2 % at 10 g/l of NaCl. No germination was recorded (0 %) at 12 g/l of NaCl.

At optimal temperature 20°C, seeds started germination after three days (Incubation Period) and was stopped after 6 to 7 days (delay germination). The same observation was recorded at 17°C. Seeds need a long latent time at 15°C and 25°C when seeds start to germinate only after 9-10 days, but it takes only one day to germinate with a very low rate of germination. Increase of salinity from 0 g/l NaCl (distilled water) to 8 g/l NaCl have no effect ($p$<0.001) on the incubation period (also three days) and delay germination (6 to 7 days). These parameters change gradually from a concentration of 10 g/l NaCl with an incubation period of 4 to 5 days and delay germination of only 2 days (Table 2).

**Table 2.** Incubation Period (IP: number of days before germination) and delay of germination (DG) of *Nigella sativa* seeds, at different temperatures and different salinity concentrations. NG: No germination observed.

| NaCl (g/l) | Temperature | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10˚C | | 15˚C | | 17˚C | | 20˚C | | 25˚C | |
| | IP | DG | IP | DG | IP | DG | IP | DG | IP | DG |
| 0 | 9 | 1 | 7 | 2 | 3 | 6 | 3 | 7 | 8 | 1 |
| 2 | 10 | 1 | 8 | 1 | 3 | 7 | 3 | 7 | 9 | 1 |
| 4 | 10 | 1 | 10 | 1 | 3 | 6 | 3 | 6 | 10 | 1 |
| 6 | NG | NG | 10 | 10 | 3 | 7 | 3 | 6 | NG | NG |
| 8 | NG | NG | NG | NG | 3 | 7 | 3 | 7 | NG | NG |
| 10 | NG | NG | NG | NG | 5 | 2 | 4 | 2 | NG | NG |

Germination in continuous darkness showed the highest rate (72.40%). It decreases thereafter according to light exposure. It is almost zero at 18 hour of light exposure and continuous light (Fig. 2). This shows that darkness is a key factor for the germination of the black cumin seeds.

Black cumin, variety Kassim, cycle started in March and finished in June- July by seed dispersion. In this study, the phenology evolution of this variety was followed from germination to the flowering stage (Table 3). Germination was achieved in 6 days by the apparition of the first spatula-shaped leaves. At 32 days, total length of seedling is about 10 cm with four pairs of lower spatula leaves and one to three upper dissected leaves. After 50 days approximately, it's the beginning of the flowering by the apparition of the first flower buttons, a long leaf petiole and the drop of the first lower spatula-leaves. All seedling growth steps are reported in Table 3.

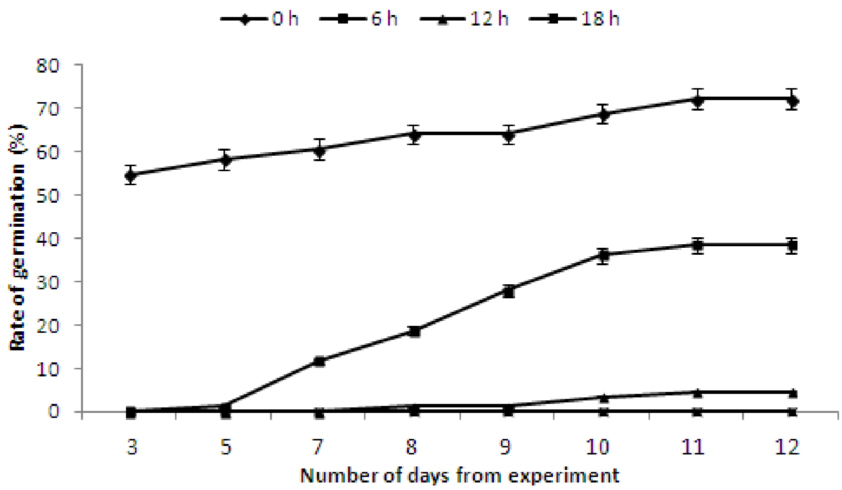


**Fig. 2**. Light effect on germination seeds of *Nigella sativa*
0h: 0h light/24h darkness; 6h: 6h light/18h dark; 12h: 12h light/12h darkness; 18h: 18h light/6h darkness

**Table 3.** Seedling Phenology and growth steps after seed germination of *Nigella sativa.*

| Days after germination | Total length (cm) | Steps of seedling growth |
|---|---|---|
| 6 | 1.0 ± 0.5 | - yang stem of 1 cm approximately<br>- apparition of two linked, small (0.5±0.2 cm), spatula-shaped leaves |
| 15 | 5.2 ± 3.1 | - elongation of stem to 4.1±2.3 cm<br>- growth of leaves with same form : spatula-shaped leaves |
| 20 | 6.1 ± 3.6 | - stem keep approximately the same length with 5.3±1.2 cm<br>- 3 to 4 pairs of linked leaves |
| 25 | 8.8 ± 2.7 | - stem at 6.5±1.5 cm<br>- 3 to 4 pair of opposite leaves<br>- elongation of petiole for leaves 2-3 cm |
| 32 | 10.1 ± 3.4 | - stem at 8.4±2.7 cm<br>- 3 to 4 pairs of lower, opposite, spatula-shaped leaves<br>- 1 to 3 upper, dissected leaves (finely divided) |
| 50 | 15.7 ± 4.3 | - stem at 10.7±3.5 cm<br>- long petiole up to 5 cm some times<br>- drop/fall of the first lower spatula-shaped leaves<br>- apparition of button flowers and the beginning of the flowering |

## 4. DISCUSSION

Temperature is the limited factor to the establishment of plants in arid regions when humidity conditions are favorable (Evans and Etherington 1990). This study shows that the germination of *Nigella sativa* was very sensitive to temperature. Optimum temperature for germination was about 20˚ C and the low decrease or increase of temperature may affect the rate of germination that will be only 2% at 25˚C and 15˚C. This result was approved for Mediterranean plants with optimal temperatures ranging between 15° and 20°C (Baskin and Baskin 1998). According to Baskin and Baskin (1998), temperature requirements for shrubs in hot semi-deserts, where *Nigella sativa* can exist, to achieve 60–100% germination, range from 15 to 35°C, with temperatures of about 20–25°C being suitable for most species. Temperature changes may affect a number of processes controlling seed vigor, including membrane permeability and the activity of membrane-bound and cytosolic enzymes (Gul and Weber 1999).

This work shows that seeds of *Nigella sativa* can germinate at high concentration of salinity. Increase of salinity from 0 to 6g/l of salt have no significant effect on germination rate which pass from 72.4% to 63.5%. Germination is slowly decreased starting from salinity of 8 g/l. These results may lead to the suggestion that, black cumin is a salt tolerant plant and may be considered as a halophyte. The same result was shown by Hajar ***et al***. (1996). Some studies have shown that black cumin is able to tolerate moderate levels of water stress (Mozzafari ***et al***. 2000). Although black cumin is cultivated in many countries, it is widely grown in arid and semi-arid regions where soils contain high levels of salts (Ashraf 2002).

However, high salinity can also completely inhibit seed germination at concentrations beyond the tolerance limits of the species (Khan ***et al***. 2001). In this work seed germination was completely inhibited at 12 g/l of salt.

Temperature can interact with salinity affecting rate of germination (El-Keblawy and Al-Rawai 2005). For *Nigella sativa*, no germinations were recorded at 10° C and 15° C and in a salt concentration of 8 g/l.

Germination of *Nigella sativa* was higher in darkness (24D: 0L) with a rate of 72.3%. Extension of light period decrease the rate of germination to 38.5% in 18D: 6L, then 4.7% in regime 12D:12L and finally completed inhibited (0%) in continuous light (0D: 24L). This result suggests that germination of *Nigella sativa* was light sensitive. This process explains that *Nigella sativa* cannot exist in open area and must be protected under trees or mountains. Ajmal and Salman (2003), working on four perennial grasses that grow in open area (dark sensitive), reported that absence of light (darkness) can inhibited the germination. In addition, light requirement for germination may vary with temperature (El-Keblawy and Al-Rawai 2005).

The phenology monitoring of *Nigella sativa*, Kassim variety, shows that germination was achieved in 6 days by the apparition of the first spatula-shaped leaves. After 50 days approximately, it's the beginning of the flowering by the apparition of the first flower buttons, a long leaf petiole and the drop of the first lower spatula-leaves. Many factors can influence seedling growth. Differences in seedling growths could be attributed to the size of seeds (Upadhaya ***et al***. 2007). However, seedling and root lengths were also highly decreased for the seeds of the same species collected from the extremely polluted area as compared to the control (Shafiq and Iqbal 2007).

## 5. CONCLUSIONS

The germination of the black cumin was very sensitive to temperature with an optimum of 20°C. Germination stops below 10°C and above 25°C. However, black cumin seeds can tolerate salinity up to until 8g/l. The absence of light shows the best rate of germination that decreased when light period increases. Seedling monitoring shows that germination was achieved after 6 days, whereas the beginning of flowering was observed after 50 days from germination.

## ACKNOWLEDGEMENTS

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# Standardization of Exam Results in Premedical Years

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***ABSTRACT:*** The achievement of students in university's preparatory/ foundational years are influenced by the nature of different subjects they study as well as the difference in their background knowledge and skills acquired in secondary schools in both rural and urban cities. This has an impact on the competition among students who need to get high scores (B or above) in order to be accepted to the college of their choice. This is an important issue in many universities adopting preparatory/foundational year's system. This system is pretty much similar to pre-university colleges in UK and USA.

This work aims at providing ways to standardize the results and minimize the external elements affecting the students' scores. A few articles are found about standardization of exams rather than standardization of results in particular. Different standardization equations are applied to the results of the physics exam. The impact of these equations on A-students, mediocre students and weak students are analyzed.

Although standardization of results improved the scores of poor students, some methods reduced the scores of high students, which may affect their chances of competition especially if they are stronger in one of the main basic science subjects and weaker in others. Performing the same procedure on the results of the three subjects (Physics, Chemistry and Biology) will give us a better view of the situation and a chance to choose the most appropriate method of standardization.

**Keywords:** Standardization of exam results, Discrepancy in standards, ranks, mean, standard deviation

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## 1. INTRODUCTION

Examinations are acceptable means to assess the cognitive skills and educational attainment of students at different levels. This allows schools to improve academic performance and might also improve cognitive skills (Finn ***et al.***, 2014). The scores in such exams may determine the future enrollment of the students into different colleges. Competition for such colleges may be based on the results of the students on their General Certificates Exams adopted in many countries or after completion of A-level exams or foundation or preparatory year. Students accepted in a preparatory/ foundational year are exposed to the same educational environment after which they compete to be accepted to the colleges of their interest. A preparatory year can help ensure a smooth transition into higher education from secondary school. (AC, 2019) It reduces the discrepancy among schools in terms of infrastructure, facilities and quality of education.

An example of this case is the foundation or preparatory year program implemented in Imam Abdulrahman Bin Faisal University in Saudi Arabia which endorsed this strategy several years ago. It was originally created to promote collaboration and integration between three faculties; Architecture, Engineering and Design and continued for other tracks. (IAU, 2019) Students are accepted into disciplines or tracks including: Health, Engineering, Science and Humanitarian tracks. Health Track is the foundational year for the medical colleges: Medicine, Dentistry, Clinical Pharmacy, Applied medical Sciences and Nursing. The goal of the majority of students is to be accepted in the colleges of Medicine or Dentistry. Nevertheless acceptance to these colleges has strict requirements. Students should get a high collective score and not less than 80% in Biology, Chemistry and Physics. A weakness of comparison of raw scores in such subjects is that it does not adjust for weakness in the language, a deterministic element in Biology, or Mathematics, which is very influential in Physics. Scores obtained by students in a certain subject can indicate the proportion of the over-all mark the student gained. Nevertheless, these scores do not account for factors such as the difficulty of the test and how the student compares to his/her colleagues neither do they account for the margin of error in the test score. (NFER, 2017)

Many articles that discuss the standardization of exams and exam questions are available, but only a few investigated the standardization of results, although the issue was discussed in the early 40's by Quazi Hossain (Motahar, 1940). This is an important issue, especially for science subjects taught in a language other than the media of instruction in high schools. Standardization of results is also of vital importance where exams are marked manually, which may lack consistency in marking amongst faculty members (AlphaPlus, 2014)

The presented work studies the different standardization methods and a curve-up method and presents the outcome of the results with the different methods.

It aims at reaching a generalized standardization method accepted by colleges or universities implementing foundational years.

## 2. METHODS

An intensive analysis was performed using the results of a physics exam marked out of 15% using the standardization methods explained below. Further analysis for the normalized and standardized results was performed using fixed average: $\bar{X}$ and standard deviation: s for both male and female students later referred to as NX and STX. The results are displayed in tables; analysis was performed using the results of:

A-students (14/15), mediocre students (7-12/15), and weak students (5/15). Students scoring below 5 out of 15 were excluded from this study since an increase in the results may unnecessarily raise scores of very poor students. For those, remedial sessions were conducted to improve their standards and comprehension of the subject.

**Standardization Methods**

Standardization of exam results, which can be described as: using the same yardstick for measuring otherwise different quantities presents a solution to such a dilemma. There are different standardization methods: these include:

1. **Using Ranks**:

The steps for standardization using ranks are summarized as: Rank the students in each subject/quiz separately and then in their totals. Add the ranks and compare these sets of ranks.

2. **Using percentiles**

This is the rank of a student per cent of the total number of students. It is calculated using the following equation

$$Percentile\ rank = \frac{Rank}{number\ of\ students} \times 100\% \quad (1)$$

**3. Using Normalization**

The word "normalization" is used informally in statistics, and so the term normalized data can have multiple meanings. In most cases, normalizing data eliminates the units of measurement for data, making it easier to compare data from different places. (Horse, 2019) The normalized method used here is transformation of data using a common z-score. Z-scores express scores not in raw points, but in relation to how everyone else on the test did. A standard or z-score measures the number of standard deviations between a raw score and the mean in standard deviations. This way standard score is defined as the distance between a raw score and its mean, in standard deviations. The z-score has a mean of zero; the marks should be adjusted by adding the mean result of students to the calculated z-value.

The standard or z-score is a very useful statistic tool because it (a) enables calculation of the probability of a score occurring within the normal distribution and (b) allows comparison of two scores that are from different normal distributions. (L. R 2019)

Factors needed to calculate the standard score include: the mean and the standard deviation of that distribution, as well as a raw score. Then we can apply the following equation:

$$z = \frac{X - X_{av.}}{s} \quad (2) \qquad \textit{(B, 2013)}$$

4. **Using a fixed mean and standard deviations**

This is another method for standardization of results, comparing two groups, for example boys and girls in the preparatory year, Health Discipline.

Standardization is performed using the following steps

a) Let $X_1$, $X_2$, …$X_n$ be the raw grades of a class and $Z_n$ the standardized score in the Physics examination. Let $Y_1$, $Y_2$,… $Y_n$be the raw grades and $W_n$ the standardized score of a student in Chemistry of the same class – in the same order.

b) Calculate the two means: $X_{av}$ and $Y_{av}$ and the two standard deviations: $\sigma_X$ and $\sigma_Y$

c) Standardize these results such that all examinations have the same mean: μ=50, for example and the same STD: s=15 (say).

$$\frac{Z_n - 50}{15} = \frac{X - \bar{X}}{\sigma_X} \quad (3)$$

So:

$$Z_n = 50 + \frac{15}{\sigma_X}(X - \bar{X}) \quad (4)$$

Similarly: $Y_n = 50 + \frac{15}{\sigma_Y}(Y - \bar{Y})$ (5)

**5. Using minimum competency level**

This system (which is not tested in this manuscript) was implemented at the Physics department, College of Medicine, University of Dammam. After the first draft of exam is prepared by the staff, each staff member examines the questions individually and puts a mark from 0-1 depending on the minimum competency level; this is an answer to: what is the mark expected to be obtained by the minimally competent student? An average of the marks stated by teachers is then obtained and the final result is multiplied by a factor decided from this calculation. There is a major drawback of this system, when applied in one subject rather than all. This will deprive the students who are stronger in this subject (who obtained 100%, which cannot be increased) from their chance to excel and thereby compete in the over-all assessment.

**6. Curve-up** This is mathematical edition of the result performed using the following equation

$$C = (10 \times \sqrt{X} - \frac{100 - X}{10}) \times 0.15 - 0.5$$

It is usually performed when the curve of the results is left-skewed to improve the results, such that the mean result of the students is above a certain value.

## 3. RESULTS

The rank of students scoring different marks (out of 15) is displayed in Table 1 below together with the percentile. Scores below 5.5/15 was not evaluated. Such students need special attention to improve in the subject. The total number of male students was 538 and that of female students was 454.

The different standardization methods are then applied to the raw data, as per score and the results are displayed in Table 2 below

**Abbreviations***:*

*R = raw data*
*C= curved-up results*
*N= Normalized*
*NX= Norm with fixed $\bar{X}$ & s*
*ST= Standardized*
*STX= Standardized with fixed $\bar{X}$ & s*

**Table 1:** Score, rank and percentile

| Grade | Males | | Females | |
|---|---|---|---|---|
| | Rank | Percentile | Rank | Percentile |
| 15.0 | - | - | 1 | 0.2 |
| 14.5 | 1 | 0.2 | 2 | 0.4 |
| **14.0** | **7** | **1.3** | **5** | **1.1** |
| 13.5 | 9 | 1.7 | 8 | 1.8 |
| 13.0 | 14 | 2.6 | 18 | 4.0 |
| 12.5 | 22 | 4.1 | 30 | 6.6 |
| 12.0 | 32 | 6.0 | 44 | 9.7 |
| 11.5 | 42 | 7.8 | 70 | 15.4 |
| 11.0 | 57 | 10.6 | 107 | 23.5 |
| 10.5 | 68 | 12.6 | 153 | 33.7 |
| **10.0** | **86** | **16.0** | **186** | **40.9** |
| 9.5 | 103 | 19.2 | 236 | 52.0 |
| 9.0 | 138 | 25.7 | 274 | 60.3 |
| 8.5 | 171 | 31.8 | 310 | 68.2 |
| 8.0 | 219 | 40.7 | 343 | 75.5 |
| 7.5 | 267 | 49.7 | 366 | 80.5 |
| 7.0 | 304 | 56.5 | 389 | 85.6 |
| 6.5 | 353 | 65.7 | 400 | 88.0 |
| **6.0** | **383** | **71.2** | **419** | **92.2** |
| 5.5 | 462 | 79.2 | 427 | 93.9 |

**Table 2:** Raw and standardized results as per score

| Grade | Males No. of students | | | | | Females No. of students | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | R | C | N&ST | NX | STX | R | C | N&ST | NX | STX |
| 15.0 | 0 | 0 | 6 | 0 | 0 | 1 | 0 | 0 | 1 | 1 |
| 14.5 | 6 | 4 | 2 | 6 | 6 | 3 | 1 | 1 | 3 | 3 |
| 14.0 | 2 | 2 | 5 | 2 | 2 | 4 | 6 | 3 | 4 | 4 |
| 13.5 | 5 | 13 | 8 | 13 | 5 | 10 | 22 | 4 | 22 | 10 |
| 13.0 | 8 | 10 | 20 | 10 | 8 | 12 | 14 | 10 | 14 | 12 |
| 12.5 | 10 | 25 | 15 | 10 | 10 | 14 | 63 | 12 | 26 | 14 |
| 12.0 | 10 | 11 | 11 | 15 | 10 | 26 | 46 | 14 | 37 | 26 |
| 11.5 | 15 | 35 | 16 | 11 | 15 | 37 | 83 | 26 | 46 | 37 |
| 11.0 | 11 | 35 | 17 | 35 | 11 | 46 | 37 | 38 | 83 | 46 |
| 10.5 | 18 | 33 | 35 | 35 | 18 | 33 | 36 | 46 | 38 | 33 |
| 10.0 | 17 | 96 | 33 | 33 | 17 | 50 | 56 | 33 | 36 | 50 |
| 9.5 | 35 | 37 | 48 | 47 | 35 | 38 | 23 | 50 | 33 | 38 |
| 9.0 | 33 | 49 | 48 | 48 | 81 | 36 | 11 | 38 | 23 | 69 |
| 8.5 | 48 | 30 | 86 | 86 | 48 | 33 | 19 | 0 | 34 | 23 |
| 8.0 | 48 | 43 | 30 | 30 | 37 | 23 | 8 | 36 | 19 | 23 |
| 7.5 | 37 | 34 | 50 | 43 | 49 | 23 | 7 | 33 | 8 | 11 |
| 7.0 | 49 | 20 | 34 | 34 | 30 | 11 | 2 | 23 | 7 | 19 |
| 6.5 | 30 | 22 | 20 | 20 | 43 | 19 | 2 | 23 | 3 | 8 |
| 6.0 | 43 | 16 | 22 | 38 | 34 | 8 | 4 | 11 | 6 | 7 |
| 5.5 | 34 | 8 | 16 | 8 | 20 | 7 | 2 | 19 | 2 | 2 |

## 4. DISCUSSION

At school level, statistical standardization or moderation is used to compare achievements in different schools in many countries including UK (NFER, 2017), USA (Randall, 2008) and (GWA, 2012) and (TISC, 2014) In Australia it is used to adjust school marks so that the moderated school marks more fairly reflect the relative standards of achievement of the two groups of students.

From the raw data displayed in Figure 1 below, the female students performed far better than the male students. The majority of female students scored above 8/15. The distribution of the score is within the normal distribution. The graphical representation of male students is left-skewed. This has been the case for many years. Female students are generally more hard-working and have higher sense of competition.

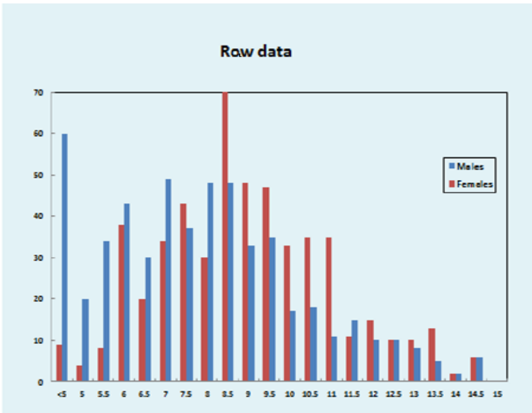


**Fig. 1:** Raw data for the results of male and female students

Figure 2 below shows the results after normalization using a fixed average and standard deviation. The scores have been increased tremendously. The distribution is now normal about 11/15 for female students and 8.5/15 for male students. This could raise an alarm that if implemented, some incompetent students may be accepted at colleges such as medicine and be responsible of the lives of their patients

Figure 3 below shows the effect of standardization using a fixed mean and standard deviation calculated from the results of the two categories.

Standardization using a fixed mean and standard deviation improved the results of the male students but reduced the results of females; since the average of female students was higher than that of male students.

This is in agreement with the findings of the online Tyari Team (OTT, 2018)

Multiplying the raw results by a certain factor, curve-up, generally improved the results of both categories except those who scored the full mark, as shown in Figure 4 below

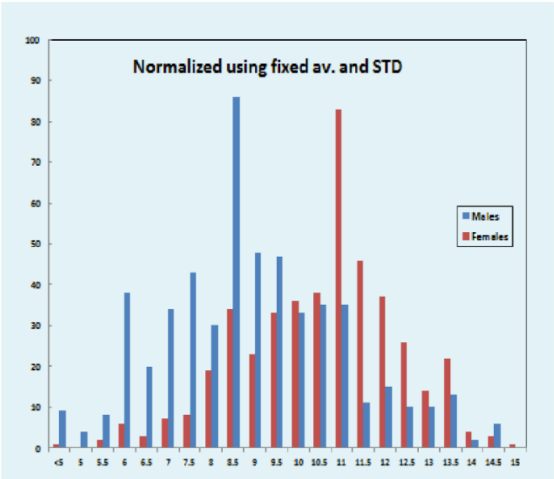


**Fig. 2:** normalized results

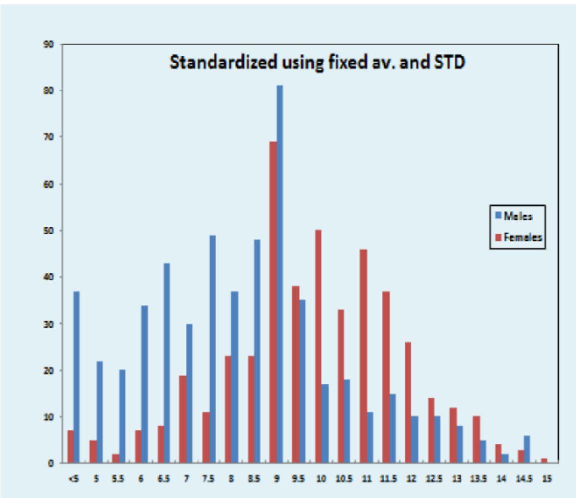


**Fig. 3:** standardized results using fixed mean and STD.

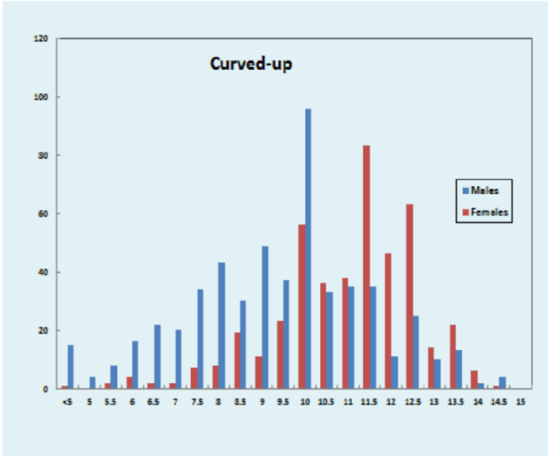


**Fig. 4:** curved-up results

Different equations applied on the raw data resulted in major changes in the scores. The effects depended on the row result. The effects on A-students, mediocre students and weak students were as follows:

**A-students (14-15/15):** Standardization using Ranks helps high standard students who performed poorly in one exam.

Normalization and standardization methods reduced the grades of "A" female-students. On the other hand, Standardization using a generalized average and STD does not affect the A-students. The curve-up reduced the results of the A+ female students who scored 15/15. N.B no male student scored the full mark.

**Mediocre students (7-12/15):** Standardization and curve-up may raise the results of mediocre students.

Standardization using a generalized average and STD increases the grades and the number of students in this category

**Weak students (5/15):** Curve-up raised the grades, but not to the extent of passing the students.

The results can be summarized in the following table:

## 5. CONCLUSIONS

Standardization may be a useful tool in pre-medical college or any foundational year. It prevents the discrepancy in the standards resulting from the large number of groups taught by a variety of teachers; and the different levels of difficulties of the exams. However, this work shows that some standardization methods unnecessarily increased the results of poor students, and reduced the score of excellent students who had the full mark. This may affect the competition in case standardization was performed in one subject only especially if the student is stronger in one of the main basic science subjects and weaker in others. Performing the same procedure on the results of the three subjects: physics, chemistry and biology together, will give us a better view of the situation and a chance to choose the most appropriate method of standardization to implement in foundational pre-medical years.

**Table 3:** Effects of curve-up and different standardization techniques:

| R | C | N(M) | N(F) | NX | ST(M) | ST(F) | STX(M) |
|---|---|---|---|---|---|---|---|
| 15.0 | 14.5 | - | 14.5 | 15.0 | - | 14.5 | 15.0 |
| 14.5 | 14.0 | 15.0 | 14.5 | 14.5 | 15.0 | 14.0 | 14.5 |
| **14.0** | **14.0** | **14.5** | **14.0** | **14.0** | **14.5** | **13.5** | **14.0** |
| 13.5 | 13.5 | 14.5 | 13.5 | 13.5 | 14.5 | 13.0 | 13.5 |
| 13.0 | 13.5 | 14.0 | 13.0 | 13.5 | 14.0 | 12.5 | 13.0 |
| 12.5 | 13.0 | 13.5 | 12.5 | 13.0 | 13.5 | 12.0 | 12.5 |
| 12.0 | 12.5 | 13.0 | 12.0 | 12.5 | 13.0 | 11.5 | 12.0 |
| 11.5 | 12.5 | 12.5 | 11.5 | 12.0 | 12.5 | 11.0 | 11.5 |
| 11.0 | 12.0 | 12.5 | 11.0 | 11.5 | 12.5 | 10.5 | 11.0 |
| 10.5 | 11.5 | 12.0 | 10.5 | 11.0 | 12.0 | 10.0 | 10.5 |
| **10.0** | **11.0** | **11.5** | **10.0** | **11.0** | **11.5** | **9.5** | **10.0** |
| 9.5 | 11.0 | 11.0 | 9.5 | 10.5 | 11.0 | 9.0 | 9.5 |
| 9.0 | 10.5 | 10.5 | 9.0 | 10.0 | 10.5 | 8.0 | 9.0 |
| 8.5 | 10.0 | 10.5 | 8.5 | 9.5 | 10.5 | 7.5 | 9.0 |
| 8.0 | 10.0 | 10.0 | 8.0 | 9.0 | 10.0 | 7.0 | 8.5 |
| 7.5 | 9.5 | 9.5 | 7.5 | 8.5 | 9.5 | 6.5 | 8.0 |
| 7.0 | 9.0 | 9.0 | 7.5 | 8.5 | 9.0 | 6.0 | 7.5 |
| 6.5 | 8.5 | 9.0 | 7.0 | 8.0 | 9.0 | 5.5 | 7.0 |
| **6.0** | **8.0** | **8.5** | **6.5** | **7.5** | **8.5** | **5.0** | **6.5** |
| 5.5 | 7.5 | 8.0 | 6.0 | 6.5 | 8.0 | 4.5 | 6.0 |
| 5.0 | 7.0 | 7.5 | 5.5 | 6.0 | 7.5 | 4.0 | 5.5 |

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# Numerical Study of Optimization of the Volume and the Emplacement of Phase Change Material Employed for Power LED Lamp Cooling

*Mohamed Bechir Ben Hamida* [1,2]

***ABSTRACT*:** The purpose of this paper is to optimize the volume and the emplacement of PCM in the heat sink for improving the cooling performance of LED with economizing of PCM amount. A numerical model is developed to simulate the PCM melting process with considering natural convection. The incorporation of PCM in the heat sink permit to reduce the junction temperature during melting time and to store an amount of energy which will be evacuated to the ambient accommodation. Different configuration of heat sink with PCM were proposed, and their temperature reduced were compared. The importance of the emplacement of PCM with the same volume was investigated.

**Keywords:** LED; Heat sink; PCM; Average temperature; Comsol Multiphysics.

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## 1. INTRODUCTION

Nowadays, light emitting diodes lamp becomes the most interesting lamp (Zhua and Sun, 2016). It replaces mercury discharge lamp (Ben Hamida ***et al.*** (2012, 2013, 2015a, 2015b)) and metal halide lamp (Ben Hamida ***et al.*** (2015c, 2016)) thanks to its instantaneous ignition, its low consumption and its high lifetime, which can reach fifty thousand hours. However, it converts more than 80% of the electric power into heat. If this heat is not properly dissipated outside, it can affect the lifetime and the luminous flux.

The first mode of heat transfer from the LED die is the conduction. For that reason, several works insisted on the important of the materials used in the packaging of the LED: Christensen ***et al.*** (2009) perform a ceramic packaging architecture to eliminate the resistance due to the epoxy isolation layer. Heo ***et al*** present an application of high thermal conductivity aluminum nitride (AlN) films to replace low thermal conductivity epoxy resin or alumina substrates (Heo ***et al.*** (2013)). Yang ***et al.*** (2014) reduce the thermal spreading resistance by 14% by using graphite substrate instead of aluminum. Ben Abdelmlak ***et al.*** (2016, 2017) notify the grave effect of thermal conduction path deficiency between the thermal grease and the heat sink. The heat sink will guaranty the dissipation of the heat by convection in the surrounding environment. Many other investigators study experimentally the effect of orientation of heat sink on the heat transfer for example Costa who upgrade radial heat sink (Costa ***et al***. 2014) and Tari ***et al.*** (2013) who gives numerical study of inclined plate fin heat sink. Huang combined pin fins and oblique fins (Huang ***et al.*** 2016). He found the two optimum number of plate fins in each model (7 in OPF oblique-plate fin heat sink and 8 in PPF pin-plate fin heat sink). Seung-Hwan Yu studied experimentally and numerically the natural convection in a radial heat sink, composed of a horizontal circular base and rectangular fins (Yu ***et al.*** 2010).

However, sometimes, passive cooling methods are deficient for the heat charge generated during long periods of manipulation due to some restrictions such as limited thermal conductivity of air for convection or small space reducing the performance. For that reason, other researchers resort to active method, Hsu and Hang showed high performance of LED with forced convection cooling fluid airflow (Hsu ***et al.*** 2016).

The problem of active method is that it requires other moving parts and additional energy. In this work, a thermal management technique for cooling LED using Phase Change Materials is proposed.

PCMs are effectively used as passive thermal energy storage for several applications such as air conditioning (Zalba ***et al.*** 2004) and glazed windows (Li ***et al.*** 2016; Lia ***et al.*** 2018). To ameliorate the PCM reliability, some works use a metal foam/PCM (Zheng ***et al.*** 2018; Esapour ***et al.*** 2018), others use multi-PCM (Aldoss ***et al.***, 2014) or composite of PCM (George ***et al.*** 2018).

## 2. GEOMETRY AND GOVERNING EQUATIONS

The figure 1 shows the simplified structure of LED package and the structure of the heat sink (Minseok ***et al.*** 2012).

The dimensions of the structure and the proprieties of materials are summarized in table 1.

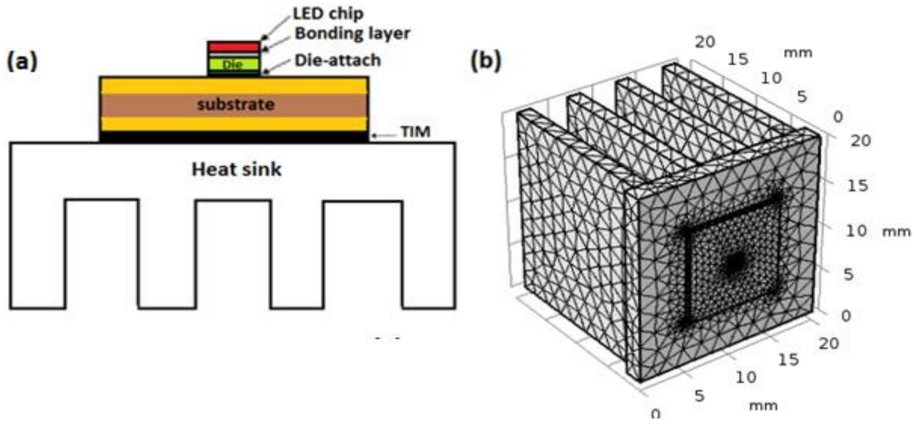



**Fig. 1:** (a) The structure of the LED package (b) Dimensions of the heat sink

**Table 1:** Structural dimensions and thermal conductivities at 25°C

| | Thickness | Size | Materials | Thermal conductivity (W/m$^2$K) |
|---|---|---|---|---|
| **LED-chip** | 4 µm | 1 mm × 1 mm | GaN | 130 |
| **Metallization** | 10 µm | | Au-Si eutectic bonding | 27 |
| **Die** | 375 µm | | Si | 124 |
| **Die-attach** | 50 µm | | Au-20Sn | 57 |
| **Substrate** | 127 µm | 1 cm × 1 cm | Copper | 385 |
| | 381 µm | | DBC : AlN | 180 |
| **TIM** | 50µm | 1 cm × 1 cm | Thermal grease | 3 |
| **Heat sink** | - | - | Al | 150 |

The energy equation is:

$$\frac{dH}{dt} = \nabla \cdot (\lambda \cdot \nabla T) \tag{1}$$

Where, H is the enthalpy and $\lambda$ the thermal conductivity of the PCM

$$H(T) = \int_{T_m}^{T} \rho \cdot C_p \cdot \partial T + \rho \cdot L_{PCM} \cdot \beta(T) \tag{2}$$

Where, $L_{PCM}$ is the latent heat of the PCM and $\beta$ is the liquid fraction expressed as:

$$\beta(T) = \begin{cases} 0 & \text{if} \quad T \le T_{sol} \\ \dfrac{(T - T_{sol})}{(T_m - T_{sol})} & \text{if} \quad T_{sol} \prec T \prec T_m \\ 1 & \text{if} \quad T \ge T_m \end{cases} \tag{3}$$

Where $T_m$ is the melting temperature and $T_{sol}$ is the solidus temperature

## 3. ASSUMPTIONS AND BOUNDARY CONDITIONS

The initial temperature is 25 °C.

On top of the die there is a uniform heat flux (q = 1 W) and other surfaces around the die, the die attach and the substrate are adiabatic.

To study the effect of a thermal shock on our LED structure, the heat transfer coefficient is taken as dropped from $h = 200 \quad W/(m^2K)$ to $h = 5 \quad W/(m^2K)$ at t = 0 s.

The thermos-physical characteristics of the PCM are independent of temperature as detailed in table 2

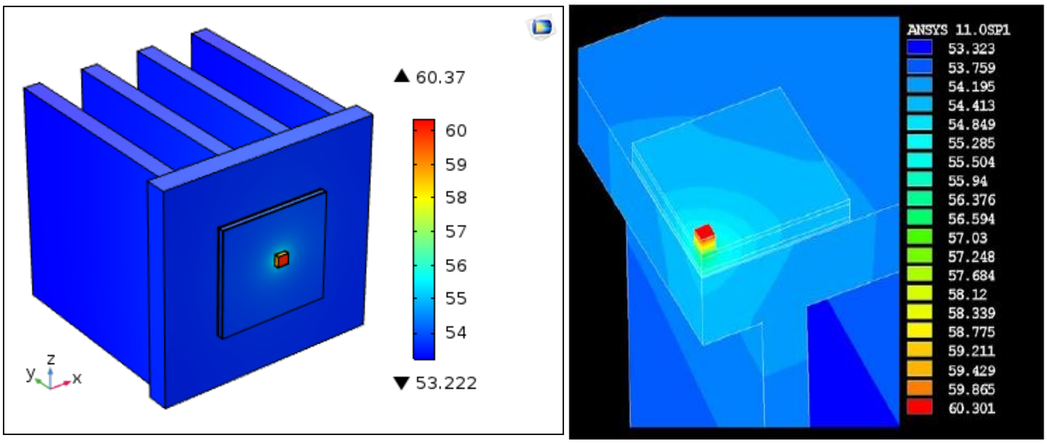
**Table 2:** Thermo-physical characteristics of RT42 (Saad ***et al***.,2013)

| | |
|---|---|
| Solidification/Melting temperature, $T_{s/m}$ | 38-42 °C |
| Latent heat of fusion, L (kJ/kg) | 165 |
| Specific heat, $C_p$ (kJ/kg K) | 2 |
| Thermal conductivity, k (W/m K) (solid); 0.2 (W/m K) (liquid) | 0.2 |
| Density, $\rho$ (kg/m$^3$) (solid); 760 (kg/m$^3$) (liquid) | 880 |
| Dynamic viscosity, $\mu$ | 0.0235 (Pa.s) |
| Coefficient of thermal expansion, $\beta$ | 0.0001 (1/K) |

## 4. NUMERICAL PROCEDURE AND VALIDATION

The commercial simulation software Comsol Multiphysics 5.3, which is based on finite technical elements, is used as the computational platform in which the applied modules are used for solving the physical model. The mesh used and adequate to satisfy the accuracy of the results contains 147836 elements. Additional elements give a difference of 0.002 $^0$C in the junction temperature.

Figure 2 shows the temperature profile of the LED package in stationary state with zero volume of PCM. With the same conditions taken by Minseok ***et al.*** (2012) : power 1 W, ambient temperature 25°C and heat transfer coefficient $h = 10 \quad W/(m^2K)$, the maximum and the minimum temperature are 60.37°C and 53.22°C respectively. Compared with those found by Minseok, which are 60.30°C and 53.32°C respectively, the difference is about 0.1%.




(a) (b)

**Fig. 2:** Temperature distribution of the LED package: (a): our code (b): Minseok [25]

## 5. RESULTS AND DISCUSSIONS

### 5.1 Incorporation of PCM in the cavities of heat sink

The initial structure of our LED heat sink was presented in figure 1 and it was given by Minseok ***et al.*** (2012): $20 \times 20 \times 2$ mm of Aluminum base attached to 4 parallel plate fins having 1,5 mm of thickness and separated by 3 cavities with 4 mm width.

For improving the thermal management of our LED devise, we consider only the symmetric emplacement to assure the uniformity of temperature distribution in the structure.

For a better study and optimization, 5 possible cases of PCM location within the cavities of heat sink heat shown in the figure 3.

## 5.2 Evolution of solid-liquid interface and time for complete melting

The figure 4 is a capture of the solid liquid interface at t = 5000 s. The figure 5 displays the evolution with time of the melt volume fraction. The red color represents fluid PCM phase, while blue for solid PCM phase.

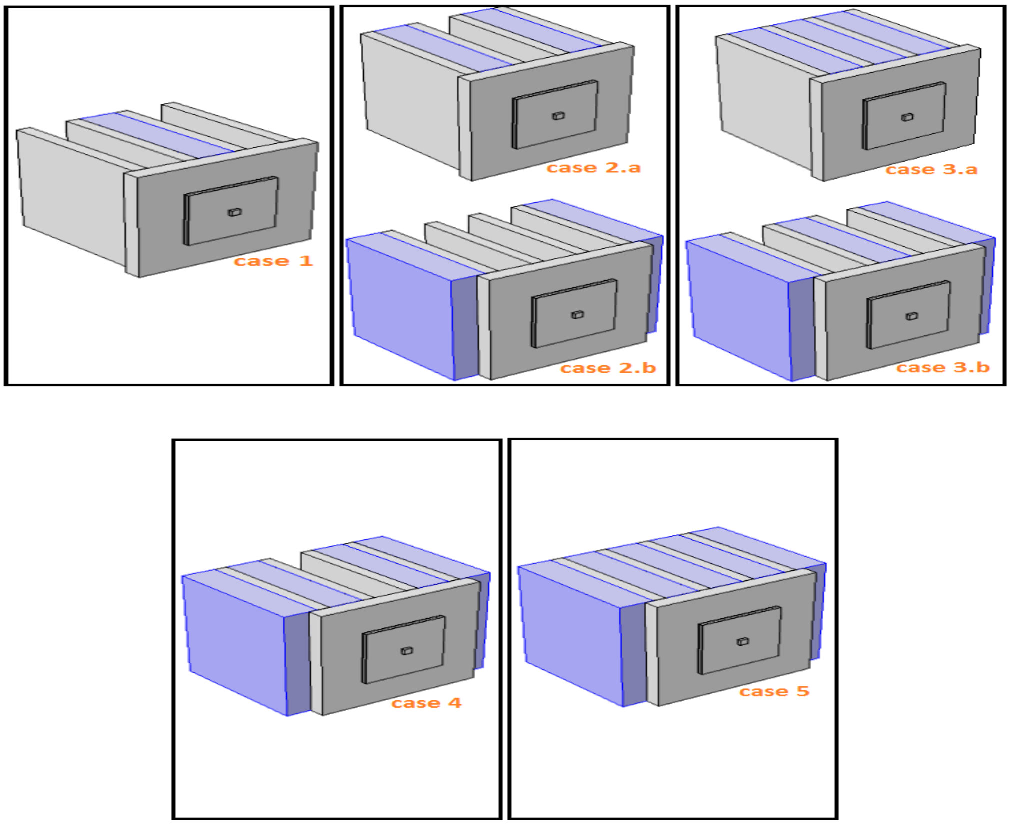



**Fig. 3:** Different configuration of LED with PCM

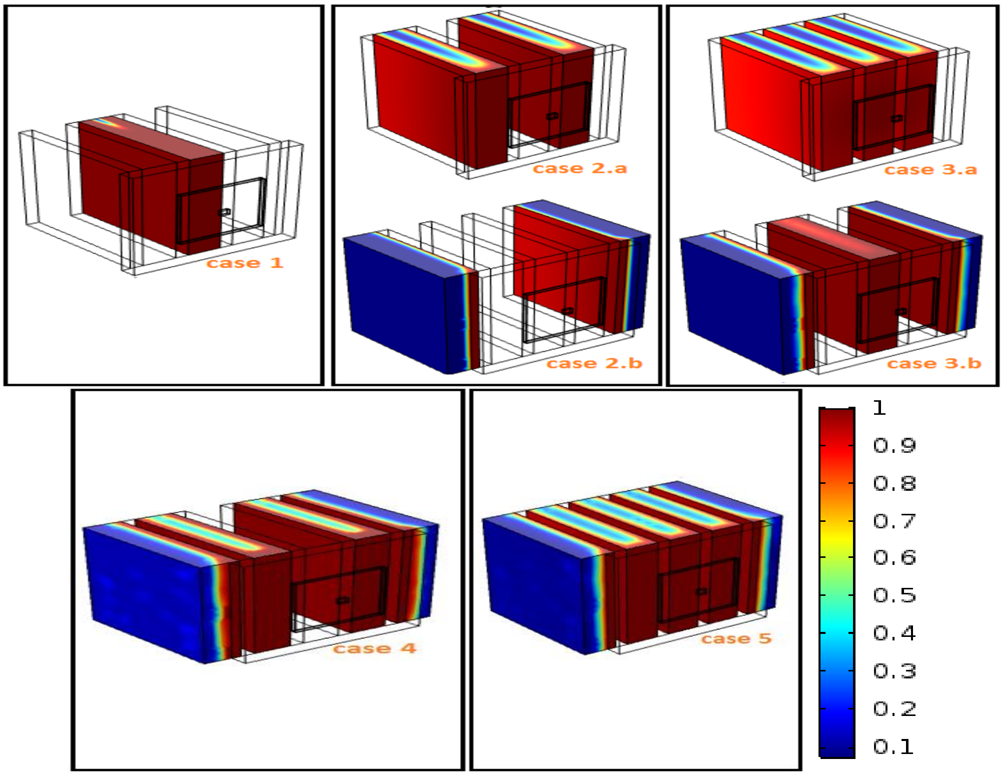



**Fig. 4:** Liquid PCM volume fraction distribution at t = 5000s

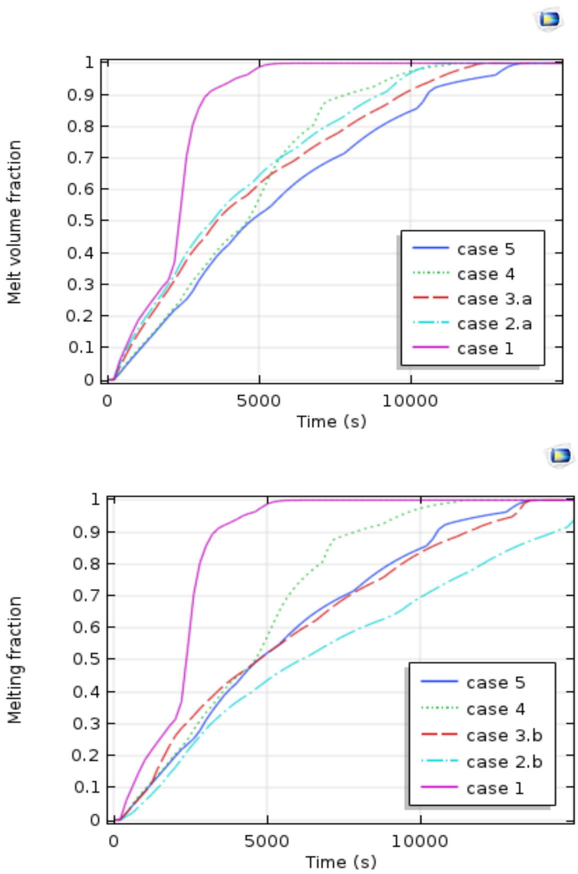



**Fig. 5:** Evolution of PCM melt volume fraction with time

From these figures, we conclude that: when the PCM is putted inside the heat sink it melts faster than when it putted outside because the majority of heat absorbed by PCM is coming from fins by conduction. If the PCM is enclosed between fins it has large surface of heat conduction. For that reason, the solid liquid interface in case 2.b moves the most slowly.

The liquid fraction of PCM starts from the base of the heat sink due to heat conduction from the base. The increase of the number of PCM layer enhances the uniformity of temperature distribution in the walls of the heat sink.

### 5.3 Transient temperature variation

Figure 6 displays the evolution of average temperature with time for different configuration of heat sink with PCM. For the case without PCM, the average temperature attains quickly the stationary temperature 54°C. For the cases with PCM, the average temperature increases moderately to the melting point of PCM. When the PCM is melting the average temperature still constant. It is reduced by 15% in case 5 and 4, with 11% in case 3 and 2 and with 5% in case 1.

Increasing the amount of PCM help to absorb more the heat and to reduce more the temperature but there is no large difference between cases from 2 to 5. There is an increase of 60% of amount of PCM but only 4% of difference in reducing the average temperature.

Therefore, we can economize on PCM and use only two layers of PCM to decrease the mass of heat sink and guaranties the same results.

When the PCM is fully melted, the average temperature will increase gradually to the steady state temperature finally. The inclusion of PCM stabilizes the average temperature at the desired value only if the PCM has not melted fully.

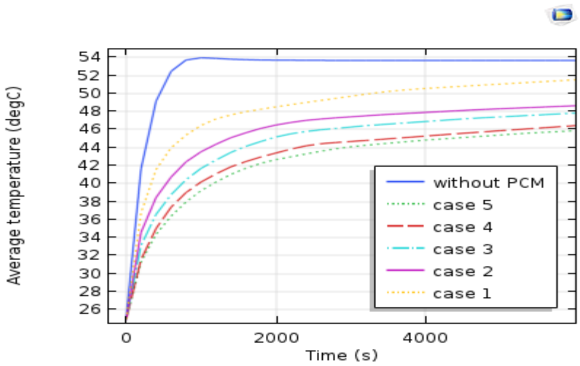



**Fig. 6:** Evolution of average temperature with time for various configurations

## 6. CONCLUSIONS

The incorporation of PCM in the heat sink of the Light emitting diodes permit the absorption of heat to delay the peak temperature and to store the energy which will be evacuated to the ambient accommodation.

To predict these numerical models is developed and validated with previously published works.

The main results of the numerical analysis led to the following conclusions:

- The central chip is the origin of heat, so using one central layer of PCM has no effect on reducing the temperature because its little volume melt very fast and it is insufficient to absorb more of heat.
- With the same volume of PCM the emplacement is very important: the layer enclosed between fins melted fast and absorb the energy faster because the heat is coming by conduction from the fin surface.
- The use of PCM in the heat sink permit the reduction of temperature by 11% with 2 or 3 layer and 15% with 4 and 5 layers.

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# Evaluation of Soil Liquefaction Potential around Enfidha International Airport, Tunisia

*Hatem Gasmi* [1,2]

**ABSTRACT**

During this last century, the examples of liquefaction caused by the earthquakes are very numerous and their consequences are responsible for several important damages. Thus, several countries are currently facing this problem and search to improve their structure design against the earthquake.

In this paper, we are interested in studying the area of Enfidha Airport, given its strategic and economic importance in the Mediterranean basin. In order to do this, and before practicing the liquefaction evaluation method, it is primordial to present the geological and seismic setting of area studied.

This research work aims to highlight the methods of recognition and to evaluate as a case study the liquefaction of the Enfidha zone using the empirical relationships between the Standard Penetration Test (SPT) and the Cone Penetration Test (CPT).

The study showed the serious existence of liquefaction risk in some areas. Thus, the liquefaction potential index values were interpreted and compared; it was observed that there was not a perfect agreement between the results of the two tests. The liquefaction potential index values using the SPT were found to be lower than those of the CPT method.

**Keywords**: earthquakes; liquefaction potential; Geotechnical Investigations; Enfidha International Airport

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## 1. INTRODUCTION

The soils liquefaction is an instability phenomenon or loss of resistance that can generally take place on a granular saturated or partially saturated medium. It is manifested by an increase in pore pressure linked to the contracting behavior of the soil during the application of swift loading (earthquake, shocks, tidal waves…). The liquefaction phenomenon is at the origin of a sudden instability of soils which flowing under the effect of gravity and the loads can cause irreparable damage to nearby structures.

After the earthquake of Alaska (1964) and Niigata in Japan (1964), Seed and Idriss (1971) developed a simplified procedure based on field tests for the evaluation of liquefaction potential. Subsequently, this procedure has undergone several modifications or improvements, notably by Seed (1979), Seed and Idriss (1983), and Seed ***et al.*** (1985).

In January 1996, a workshop on liquefaction problems was organized by the National Center for Earthquake Engineering Research (NCEER); the recommendations of this workshop are analyzed by Youd ***et al***. (2001). Currently, the liquefaction study has developed to become a completely separate area of research (Andrusa ***et al.***, 2004; Monaco ***et al***., 2005; Grasso and Maugeri, 2006; Tsai ***et al***., 2009).

Generally, cyclic shear stresses could be assessed through simplified procedures (Seed, 2010) or based upon results of a site response analysis. The cyclic shear resistance of soils could be evaluated in the laboratory or based upon empirical relationships using in-situ material parameters e.g., SPT, CPT, or Vs (Finn, 2002; Ali ***et al.***, 2014; Shelley ***et al.***, 2015).

Pathak and Dalvi (2011) have already developed similar such model "model A" separating "yes " and " no" zones of liquefaction based on field performance data. Further, these authors have also invented a method to evaluate triggering acceleration indicating initiation of liquefaction.

Numerous cases of runoff, cited in the literature, in natural soil media and artificial structures, have been attributed to liquefaction, for example: Fort Peck Dam (1938), Niigata in Japan (1964), Moss Landing, California (1989), Chi-Chi, Taiwan (1999), Adapazari, Turkey (1999), Boumerdes, Algeria (2003), Christchurch, New Zealand (2011), ...

Soil liquefaction can therefore result from seismic stress; the induced deformations, even moderate, can render certain structures unfit. Hence the interest of seriously examining the liquefaction potential of a given site, in this case Tunisia, knowing that this phenomenon was observed during the Sidi Thabet earthquake of 1 December 1970 for a moderate magnitude of 5.1. Since this event, the government has given increasing importance to this phenomenon especially as regards the mega projects that is the case of Enfidha International Airport.

The purpose of this project is therefore to identify the underground liquefaction potential of Enfidha city, using the most current methods.

## 2. STUDY AREA

### 2.1 Geographical setting

The study area is part of northeastern Tunisia. It is approximately between 10 ° and 11.5 ° south latitude and between 35 ° and 36.30 ° east longitude. It is bounded on the west by the Zaghouan faults corridor which separates it from the Atlas domain. In this region, from south to north we find the following structures: Jebel Souatir, Fadhloun, Garci, Mdeker, the eastern flank of the Saouaf syncline, the massifs between Jradou and Takrouna.

## 2.2 Geological setting and Seismicity of the region

The study area includes the Enfidha block in the North which corresponds to a folded and faulted zone. According to Burollet (1981), the geological structures of Enfidha are closely linked to the North-South axis. This axis corresponds to a deep suture due to the heterogeneities of the base. It separates an unstable domain in the West and a stable domain in the East. It is considered as a bumper on which are molded and struck the atlastic folds. It is a zone with a great reduction of thickness and many discrepancies.

The region consists of areas that are moderately unstable on the seismic plane. According to the historical seismicity the destructive earthquakes have a periodicity of about four centuries. The liquefaction potential of soils should be examined for PGA within a range from 0.05g to 0.3g.

## 3.GEOTECHNICAL INVESTIGATIONS

For this study, we have the results of geotechnical surveys carried out on 25 sites. The first step in our work was the consolidation of a geotechnical database including: 105 core drilling; 59 pressuremeter tests; 41 Standard penetration test (SPT); and 58 Cone Penetration Tests (CPT);

The available data are recent and spread over the different areas mentioned above. All data has been stored and managed using RockWorks software, which also provides a representation of the layers in place. Figure.1 shows the location of these data in georeferenced coordinates.

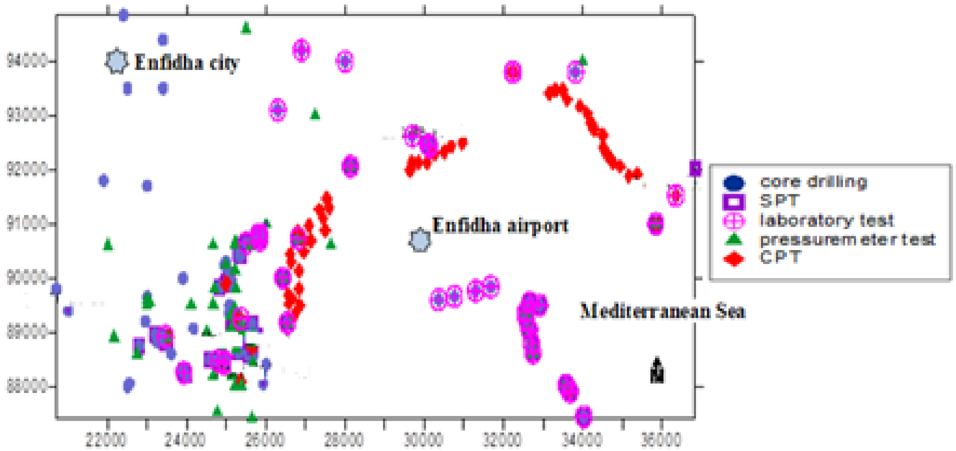



**Fig. 1:** Location of geotechnical tests

The subsoil of the study area is complex and extremely variable;

The subsoil is chaotic and characterized by a compact clay substratum of variable depth from 10 to 60 m. The layers overlying the substratum are also of varying thicknesses and depths, as shown by subsequent sections made in different areas using RockWorks (Figures 2).

- At Enfidha downtown site (Figure.2.a), we identify (from bottom to top) a layer of tufous clay, a layer of gray plastic clay, an alternation of layers of clay, sand and silt, a thick layer of silt (about 25 m) and finally a superficial layer of backfill.
- Figure.2.b shows a section along the Enfidha airport runway; the following layers are identified (from bottom to top): a layer of reddish clay, a sandstone lens, a layer of sandy yellowish clay, a layer of gray plastic clay, a layer of sandstone sand, alternating layers of clay, sand and silt finally a layer of fill.

- At Enfidha Sea coast, and according to the section shown in Figure.2.c, the subsoil consists from the bottom to the top of: gray plastic clay, a layer of sand then alternating layers of clay and sand silt with sandstone passages, a layer of sand, a layer of silt and finally a superficial layer of backfill.
- As shown in the section of the subsoil located at The Sabkha of Assa Juriba shown in Figure.2.d (from bottom to top), we encounter: a layer of sandstone sand, a layer of sandy yellowish clay and finally a layer of backfill.

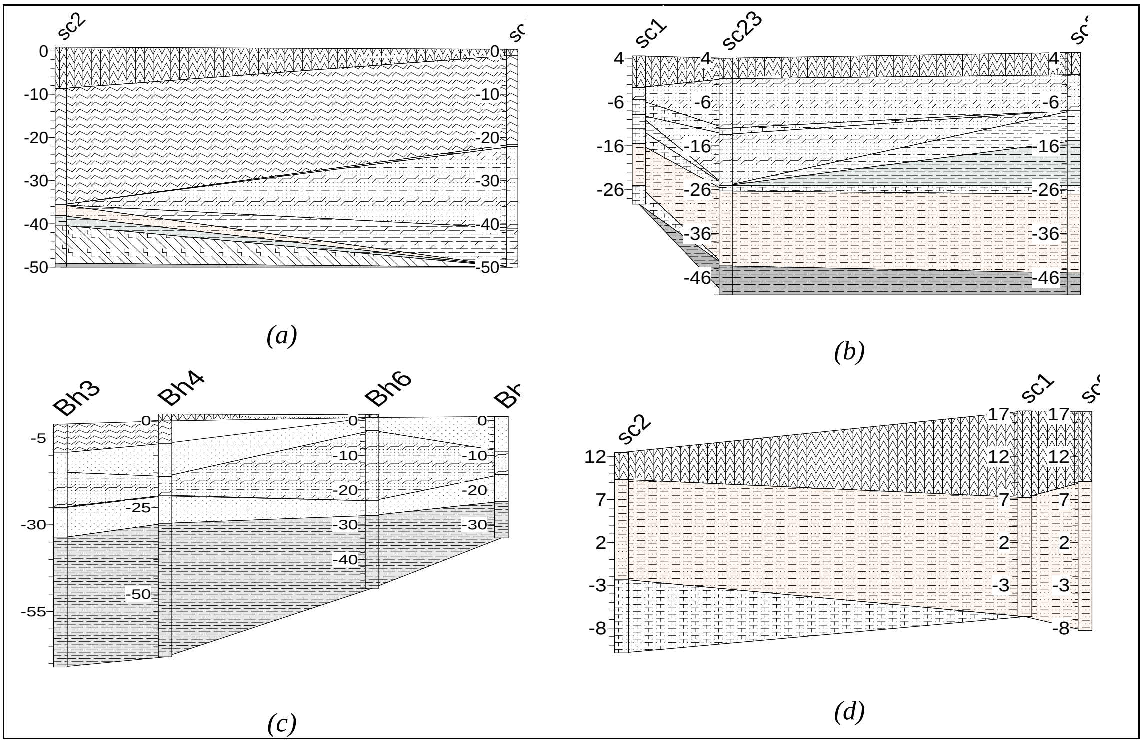



**Fig. 2:** subsoil cross-section illustrating studied sites: (a) Enfidha downtown area; (b) Enfidha airport area; (c)Enfidha Sea coast; (d) sabkha of Assa Juriba area

## 4. THE USED METHODOLOGY

The methodology used for this study is inspired by the recommendations of the French Association of Parasismic Engineering (AFPS, 1993) which dictates three levels of evaluation;

### 4.1. Level A

A first qualitative study of liquefaction sensitivity will result from the exploitation of geological and hydrogeological data as well as soil characteristics independently of the seismic hazard.

#### 4.1.1. Identification of liquefiable soils

The identification is done according to the criteria of Seed ***et al***. (2003). These criteria classify soils based on soil index parameters. Soils, which satisfy all three following conditions: (i) PI < 12, (ii) LL < 37 and (iii) wc /LL > 0.8 fall into Zone A and considered to be potentially liquefiable. Soils lie in Zone B, i.e. satisfying the following conditions: (i) 12 < PI < LL < 47 and (iii) wc /LL > 0.85, are classified to be moderately susceptible to liquefaction and need further testing. Soils lie out of these boundaries (named as Zone C) are not considered to be susceptible to "classical" liquefaction.

### 4.1.2. Geological and hydrogeological characteristics of the site

In addition to the criteria outlined above, the following criteria based on geology and piezometric level will be added to assess susceptibility to liquefaction (Table.1).

**Table 1:** Susceptibility of sedimentary deposits to liquefaction according to the nature and age of the deposit (Seed ***et al.*** 2003)

| **Nature of deposit** | **Possibility of occurrence of liquefaction of saturated powdery soils** | | | |
|---|---|---|---|---|
| | **< 500 ans** | **Holocene < 10000 years** | **Pleistocene < 1650000 years** | **Pre-Pleistocene > 1650000 years** |
| **Dépôts continentaux** | | | | |
| **River** | Very high | High | low | Very low |
| **Alluvial plain** | High | Moderate | Low | Very low |
| **Wind deposits** | High | Low | Low | Very low |
| **Marine terraces** | Moderate | Low | Low | Very low |
| **deltas** | - | Moderate | Very low | Very low |
| **Lacustrine deposits** | High | Moderate | Low | Very low |
| **colluvial** | High | Moderate | Low | Very low |
| **dunes** | High | Moderate | Low | Very low |
| **Loess** | High | High | High | Inconnue |
| **Glacial moraine** | Low | Low | Very low | Very low |
| **Coastal areas** | | | | |
| **deltas** | Very high | High | Low | Very low |
| **estuaries** | High | Moderate | Low | Very low |
| **beaches** | Moderate to High | Moderate to Low | Low to Very low | Very low |
| **lagoons** | High | Moderate | Low | Very low |
| **Artificial fillings** | | | | |
| **Not compacted** | Very high | - | - | - |
| **compacted** | Low | - | - | - |

The purely geological or morphological analyzes make it possible to map the susceptibility of a deposit to liquefaction. Only the consideration of the mechanical characteristics and those of the seismic movement allows a real estimate of the liquefaction potential.

## 4.2. Level B

Level B studies will use the mechanical characteristics of soils. These studies are based on the comparison between cyclic resistance ratio (CRR) expressed as a function of the mechanical characteristics of soils and the cyclic loading intensity, expressed by the uniform duty cycle stress ratio (CSR).

### 4.2.1. Cyclic Stress Ratio (CSR)

The expression for the CSR induced by earthquake ground motions formulated by Idriss and Boulanger (2004) is as follows:

$$CRS = \left(\frac{a_{max}}{g}\right).\left(\frac{\sigma_v}{\sigma'_v}\right).r_d.\frac{1}{MSF}\frac{1}{K_\sigma} \times 0.65 \quad (1)$$

the $a_{\max}$ is the peak horizontal ground acceleration; $g$ is the acceleration of gravity; $\sigma_V$ and $\sigma'_V$ are total vertical overburden stress and effective vertical overburden stress, respectively, at a given depth below the ground surface; $r_d$ is the depth-dependent stress reduction factor; MSF is the magnitude scaling factor; and $K_\sigma$ is the overburden correction factor.

For z depth of investigation and M magnitude of earthquake, the stress reduction factor ($rd$) is given by:

*If z ≤ 34 m*
$$\begin{cases} Ln(r_d) = \alpha(z) + \beta(z)M \\ \alpha(z) = -1.012 - 1.126 \sin(\frac{z}{11.73} + 5.133) \\ \beta(z) = 0.106 - 0.118 \sin(\frac{z}{11.28} + 5.142) \end{cases} \quad (2)$$

*If z > 34 m*
$$r_d = 0.12 \exp(0.22\, M) \quad (3)$$

The magnitude scaling factor (MSF) is as follows:

$$MSF = 6.9 \exp(\frac{M}{4}) - 0.058 \leq 1.8 \quad (4)$$

Concerning the overburden correction factor $K_\sigma$ is given by:

- For SPT
$$\begin{cases} k_\sigma = 1 - C_\sigma Ln(\frac{\sigma'_{v0}}{P_a}) \\ C_\sigma = \frac{1}{18.9 - 2.55\sqrt{N_{1.60}}} \\ k_\sigma \leq 1.0 \quad and \quad C_\sigma \leq 0.3 \end{cases} \quad (5)$$

Were $Pa$ is the atmospheric pressure and $N_{1,60}$ is the corrected SPT blow count.

- For CPT
$$\begin{cases} k_\sigma = 1 - C_\sigma Ln(\frac{\sigma'_{v0}}{P_a}) \\ C_\sigma = \frac{1}{37.3 - 8.27\,(q_{c1N})^{0.264}} \\ k_\sigma \leq 1.0 \quad and \quad C_\sigma \leq 0.3 \end{cases} \quad (6)$$

Were $q_{c1N}$ is the corrected CPT cone resistance

**4.2.2. Evaluation of the Cyclic Resistance Ratio (CRR).**

- Using SPT:

$$CRR = exp\left(\frac{N_{1,60,cs}}{14.1} + \left(\frac{N_{1,60,cs}}{126}\right)^2 - \left(\frac{N_{1,60,cs}}{23.6}\right)^3 + \left(\frac{N_{1,60,cs}}{25.4}\right)^4 - 2.8\right) \quad (7)$$

With $N_{1.60.cs}$ is the number of blows corrected for fine content determined by:

$$N_{1,60,cs} = N_{1,60} + \Delta(N_{1,60}) \quad (8)$$

$$\Delta N_{1,60} = \exp(1.63 + \frac{9.7}{FC} - (\frac{15.7}{FC})^2) \quad (9)$$

With FC is the fines content (in percentage).

- Using CPT:

$$CRR = exp\left(\frac{q_{C1N}}{540} + \left(\frac{q_{C1N}}{67}\right)^2 - \left(\frac{q_{C1N}}{80}\right)^3 + \left(\frac{q_{C1N}}{114}\right)^4 - 3\right) \quad (10)$$

$q_{c1N}$ is the CPT corrected cone resistance determined by:

$$\begin{cases} q_{C1N} = \frac{C_N q_c}{Pa} \\ C_N = \left(\frac{P_a}{\sigma'_v}\right)^{\beta} \leq 1.7 \\ \beta = 1.338 - 0.249(\,q_{C1N})^{0.264} \end{cases} \quad (11)$$

#### 4.2.3. The Safety factor FS

The safety factor results from the comparison of the *Cyclic Stress Ratio* generated by the earthquake and the *Cyclic Resistance Ratio* of the soil.

$$FS = \frac{CRR}{CSR} \quad (12)$$

- $FS \geq 2$ : Area not liquefiable
- $1.5 \leq FS < 2.0$ : Liquefaction unlikely
- $1.0 \leq FS < 1.5$ : Liquefaction likely
- $FS < 1.0$ : Almost certainly liquefaction

### 4.3. Level C

The level C studies are distinguished from level B by the volume of the reconnaissance involved. It is desirable to carry out additional drilling with the completion of SPT and CPT tests. Intact samples will be taken from suspect formations. The cyclic shear stress induced by seismic loading is calculated by dynamic wave propagation calculations.

For these analyzes, the history of representative seismic risk accelerations in a site is used to define the ground movements, in the case of Enfidha according to the seismic hazard: $a_{max}$ = 0.05g, 0.1g, 0.15g and 0.2g. For this, we can use specialized software programs of determination of nonlinear site response, such as SUMDES (Li ***et al***., 1992), D-MOD (Matasovic, 2004), NERA (Bardet and Tobita, 2001) and Dissim (Gasmi ***et al***., 2014).

Once the value of the equivalent stress is obtained, we repeat the same calculations performed at level B (Cyclic Stress Ratio and Cyclic Resistance Ratio, finally a safety factor).

## 5. RESULTS AND DISCUSSIONS

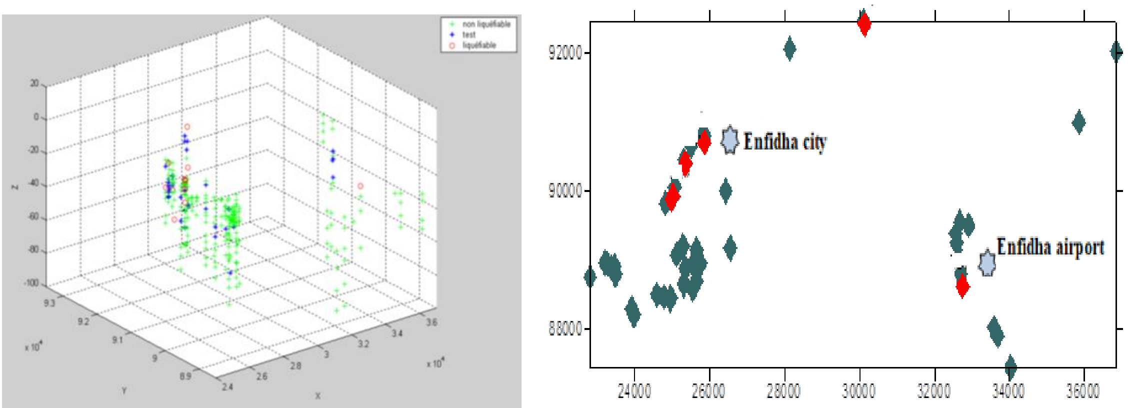
### 5.1. Study according to level A

#### 5.1.1. Identification of liquefiable soils

The samples available and exploited for this level of study are taken exclusively in clay soils. These samples are taken at different depths; we have therefore represented the results spatially in a georeferenced 3D diagram (figure.3.a). The green color indicates non-liquefiable soil, the red color indicates a confirmed risk of liquefaction, and the blue color represents soils that require further investigation.

The results of the identification of liquefiable soils according to level A are shown in figure.3.b and showed that:

- The majority of the samples examined are non-liquefiable (shown in green);
- Some samples proved to be liquefiable (points in red) at the Enfidha city: the museum area (at depths of 1.5m and 11m), at the gates of the city (depth 19m), the hospital area (depth 31m), airport (depth 16m) and seaside (depth 8m and 13m).
- Other samples (shown in blue) require extensive studies.




(a) (b)

**Fig. 3:** liquefaction risk based on level A identification: (a) georeferenced 3D diagram; (b) Sample location (Sites with a confirmed risk of Level A liquefaction are shown in red)

### 5.1.2. Geological and hydrogeological characteristics of the site

In the level A study, we referred to geotechnical zoning studies of the area and dating of shallow muds.

Imed Hezzi (2014) dated the muddy surface formations (first 7 meters) as follows (bottom to top):

- A layer of sandstone dating back 8000 years deposited in the middle of Sabkha.
- A layer of greenish-gray mud dating back to 6900 years corresponding to a deposit in an open marine environment.
- A layer of gray and greenish mud dating from 3130 years.
- Finally, a final layer of mud of later age (thickness: 1.5 m).

In term of sedimentological, a 7m thick mud deposit in 8000 years corresponds to an average annual rate of 0.9 mm.

The geotechnical zoning has given the following results:

**Table 2:** Results of the level A study

| Geotechnical zone | Depth of layers | origin | Age of deposit (years) | Susceptibility to liquefaction from | |
|---|---|---|---|---|---|
| | | | | Age of deposit | The age of the deposit and the depth of the water table |
| Zone I | de 0 à 5 m | backfill | from 0 to 700 | low | High |
| | de 1 à 20m | lagoon | from 1000 to 20000 | moderate | High |
| Zone II | de 0 à 15m | alluvial | Pleistocene | low | very low |
| Zone IV | de 0 à 20m | alluvial | Holocene | moderate | moderate |
| Zone V | de 0 à 15m | lagoon | pre-pleistocene | very low | very low |

### 5.2. Study according to level B

Susceptibility to liquefaction was examined for maximum surface accelerations of 0.1g to 0.3g; It is represented by the safety factor FS = $\frac{CRR}{CSR}$ calculated step-by-step using Worksheets in Excel, the results are recorded (1) spatially in a 3D georeferenced diagram and (2) by means of sections made in a GIS environment, at different depths up to 20m (z = 0, -5, -10, -15, and -20m).

We consider Bh1 test as a calculation example at the airport runway for $a_{max}$ = 0.2g and M = 5.6. As shown in Table.3, we start the study by introducing the necessary data into an Excel Worksheets (pink ranges): $a_{max}$, magnitude, SPT number of blows, corresponding depth, water table level, soil density, material characteristics and percentage in fine. After a step-by-step calculation, the value of the safety factor for a given depth and the susceptibility to liquefaction according to the study at level B (range in orange) are obtained.

The results were represented in an S.I.G environment using ArcView. Some examples for Risk of liquefaction estimated according CPT and SPT are given in Figure.4.

In conclusion, level B studies have shown the presence of layers of sand that can liquefy; they are located in superficial formations characterized by an alternation of clay sand and mud. We have shown that the risk of liquefaction increases with the maximum acceleration on the soil surface (amax), knowing that it varies between 0.2g and 0.3g for return periods ranging from 200 to 500 years.

**Table 3:** Excel worksheet calculating susceptibility to liquefaction using the SPT test according to level B

| SPT | amax = | 0,214 | g | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | M = | 6,8 | | | | | | | | | | |
| | Pa = | 1 | atm | | | | | | | | | |
| sondage | N SPT | Z (m) | eau nappe | é humide(K | N1 | matériel*** | N1,60 | s(%)<=0.074 | N1.60.cs | CSR | RCC | FS | liquéfaction |
| Bh01 | 2 | 1 | 0,7 | 19,8 | 3,4 | 0,975 | 3,315 | 44 | 8,91706528 | 0,13588741 | 0,1106561 | 0,81432193 | L quasi certaine |
| | 2 | 2 | 0,7 | 19,8 | 3,4 | 0,975 | 3,315 | 44 | 8,91706528 | 0,1695818 | 0,1106561 | 0,65252345 | L quasi certaine |
| | 4 | 3 | 0,7 | 19,8 | 6,8 | 0,975 | 6,63 | 36 | 12,1548248 | 0,18335471 | 0,13361018 | 0,72869783 | L quasi certaine |
| | 4 | 4 | 0,7 | 19,8 | 6,37058248 | 0,975 | 6,21131792 | 36 | 11,7361428 | 0,18969798 | 0,13050078 | 0,68793976 | L quasi certaine |
| | 3 | 5 | 0,7 | 19,8 | 4,34811185 | 0,975 | 4,23940905 | 36 | 9,76423389 | 0,19238277 | 0,11642811 | 0,60518989 | L quasi certaine |
| | 1 | 6,45 | 0,7 | 19,8 | 1,29173566 | 0,975 | 1,25944227 | 36 | 6,7842671 | 0,19274092 | 0,09684789 | 0,50247707 | L quasi certaine |
| | 1 | 7,45 | 0,7 | 19,8 | 1,18022911 | 0,975 | 1,15072338 | 36 | 6,67554822 | 0,19150785 | 0,09617258 | 0,50218609 | L quasi certaine |
| | 32 | 8,55 | 0,7 | 20,1 | 32,9277104 | 0,975 | 32,1045176 | 52 | 37,719177 | 0,18684196 | 2,10668046 | 11,2752002 | non liquéfiable |
| | 6 | 10 | 0,7 | 20,1 | 5,7740125 | 0,975 | 5,62966219 | 52 | 11,2443215 | 0,18379823 | 0,12690458 | 0,6904559 | L quasi certaine |
| | 12 | 11,5 | 0,7 | 20,1 | 10,8115199 | 0,975 | 10,5412319 | 52 | 16,1558912 | 0,1813903 | 0,16614564 | 0,91595659 | L quasi certaine |
| | 14 | 13 | 0,7 | 20,1 | 11,9000533 | 0,975 | 11,602552 | 52 | 17,2172113 | 0,17821656 | 0,17597341 | 0,98741333 | L quasi certaine |
| | 6 | 14 | 0,7 | 20,1 | 4,73786872 | 0,975 | 4,61942201 | 52 | 10,2340813 | 0,17409047 | 0,11969911 | 0,68756844 | L quasi certaine |
| | 2 | 15,5 | 0,7 | 20,1 | 1,43515925 | 0,975 | 1,39928027 | 52 | 7,01393961 | 0,16867873 | 0,09828386 | 0,58266892 | L quasi certaine |
| | 6 | 17 | 0,7 | 20,1 | 4,2001336 | 0,975 | 4,09513026 | 52 | 9,7097896 | 0,1648922 | 0,11605231 | 0,70380716 | L quasi certaine |
| | 4 | 18,5 | 0,7 | 19,2 | 2,76936726 | 0,975 | 2,70013308 | 95 | 8,20038201 | 0,1658914 | 0,10589938 | 0,63836567 | L quasi certaine |
| | 4 | 20,5 | 0,7 | 19,2 | 2,58795531 | 0,975 | 2,52325642 | 95 | 8,02350536 | 0,15963242 | 0,10474337 | 0,65615352 | L quasi certaine |
| | 5 | 22 | 0,7 | 19,2 | 3,11909717 | 0,975 | 3,04111974 | 95 | 8,54136867 | 0,15548336 | 0,10814805 | 0,6955603 | L quasi certaine |
| | 5 | 23,5 | 0,7 | 19,2 | 2,98549273 | 0,975 | 2,91085541 | 95 | 8,41110434 | 0,15139518 | 0,10728589 | 0,70864802 | L quasi certaine |
| | 100 | 25 | 0,7 | 19,2 | 96,846021 | 0,975 | 94,4248704 | 95 | 99,9251194 | 0,18671152 | 1,5702E+73 | 8,4097E+73 | non liquéfiable |
| Bh02 | 3 | 10,5 | 0,8 | 19,5 | 2,88154283 | 0,975 | 2,80950426 | 74 | 8,37211913 | 0,18536219 | 0,10702862 | 0,57740264 | L quasi certaine |
| | 11 | 12 | 0,8 | 19,5 | 9,94147 | 0,975 | 9,69293325 | 74 | 15,2555481 | 0,18286708 | 0,15828289 | 0,86556252 | L quasi certaine |
| | 5 | 13,5 | 0,8 | 19,5 | 4,14954831 | 0,975 | 4,0458096 | 74 | 9,60842447 | 0,1783486 | 0,11535442 | 0,64679185 | L quasi certaine |
| | 7 | 15 | 0,8 | 19,5 | 5,50769853 | 0,975 | 5,37000607 | 74 | 10,9326209 | 0,17434822 | 0,12465583 | 0,71498193 | L quasi certaine |
| | 5 | 16,55 | 0,8 | 19,5 | 3,65832426 | 0,975 | 3,56686615 | 74 | 9,12948102 | 0,16920732 | 0,11208819 | 0,6624311 | L quasi certaine |
| | 6 | 19,5 | 0,8 | 19,5 | 3,98823652 | 0,975 | 3,88853061 | 74 | 9,45114548 | 0,16029225 | 0,11427615 | 0,71292372 | L quasi certaine |
| | 60 | 24 | 0,8 | 20,1 | 47,3239516 | 0,975 | 46,1408528 | 52 | 51,7555121 | 0,18532342 | 2276,49881 | 12283,9242 | non liquéfiable |
| | 23 | 25 | 0,8 | 20,1 | 14,3948451 | 0,975 | 14,034974 | 52 | 19,6496333 | 0,14738834 | 0,20166946 | 1,36828641 | L probable |
| Bh03 (en mer | 3 | 7,5 | -1,2 | 17,3 | 4,40708056 | 0,975 | 4,29690355 | 42 | 9,8882427 | 0,26866018 | 0,11728658 | 0,43656108 | L quasi certaine |
| | 20 | 9,5 | -1,2 | 17,3 | 23,4256385 | 0,975 | 22,8399976 | 42 | 28,4313367 | 0,25273805 | 0,40200053 | 1,59058176 | L peu probable |
| | 19 | 11,5 | -1,2 | 17,3 | 20,6375775 | 0,975 | 20,1216381 | 42 | 25,7129772 | 0,23837609 | 0,30792525 | 1,29176229 | L probable |
| | 11 | 13,5 | -1,2 | 17,3 | 11,1632858 | 0,975 | 10,8842037 | 42 | 16,4755428 | 0,22505012 | 0,16903632 | 0,75110524 | L quasi certaine |
| | 6 | 15 | -1,2 | 18,6 | 5,17636595 | 0,975 | 5,0469568 | 96 | 10,5444697 | 0,19986453 | 0,12188761 | 0,60985114 | L quasi certaine |
| | 8 | 20 | -1,2 | 18,5 | 5,86364692 | 0,975 | 5,71705575 | 95 | 11,2173047 | 0,1796849 | 0,12670874 | 0,7051719 | L quasi certaine |
| | 59 | 24,5 | -1,2 | 18,5 | 49,2026558 | 0,975 | 47,9725894 | 97 | 53,4673925 | 0,19771841 | 9681,23893 | 48964,7835 | non liquéfiable |
| | 67 | 25,5 | -1,2 | 18,5 | 57,0612297 | 0,975 | 55,634699 | 97 | 61,129502 | 0,19670725 | 61853472,6 | 314444300 | non liquéfiable |
| Bh04 | 1 | 4 | 0,5 | 19,8 | 1,7 | 0,975 | 1,6575 | 44 | 7,25956528 | 0,1982816 | 0,09983347 | 0,50349338 | L quasi certaine |
| | 1 | 6 | 0,5 | 19,8 | 1,37914897 | 0,975 | 1,34467025 | 44 | 6,94673553 | 0,19900345 | 0,09786237 | 0,49176221 | L quasi certaine |

il1 / Feuil2 / Feuil3 /

### 5.3. Study according to level C

For the C level study, the risk of liquefaction was examined for different levels of solicitations from a deterministic study of seismic hazard in the region.

The estimation of the induced ground shear stresses will be done by means of a one-dimensional seismic analysis which considers a viscoelastic behavior of the formations in place. The calculation was done using the software EERA (EERA, 2000); it provides the stress levels induced by the earthquake along the lithostratigraphic section considered. These results allow the estimation of the safety factor FS. An example of calculation is given.

The computational accelerogram is that of the Monastir earthquake, which occurred on October 18, 2013 and has duration of 16.6 seconds (recorded with a sampling rate of 0.005s); the maximum acceleration is calibrated to respective maximum levels of 0.05g, 0.1g, 0.15g, 0.2g and 0.3g in accordance with the levels expected by the deterministic study of the regional seismic hazard.

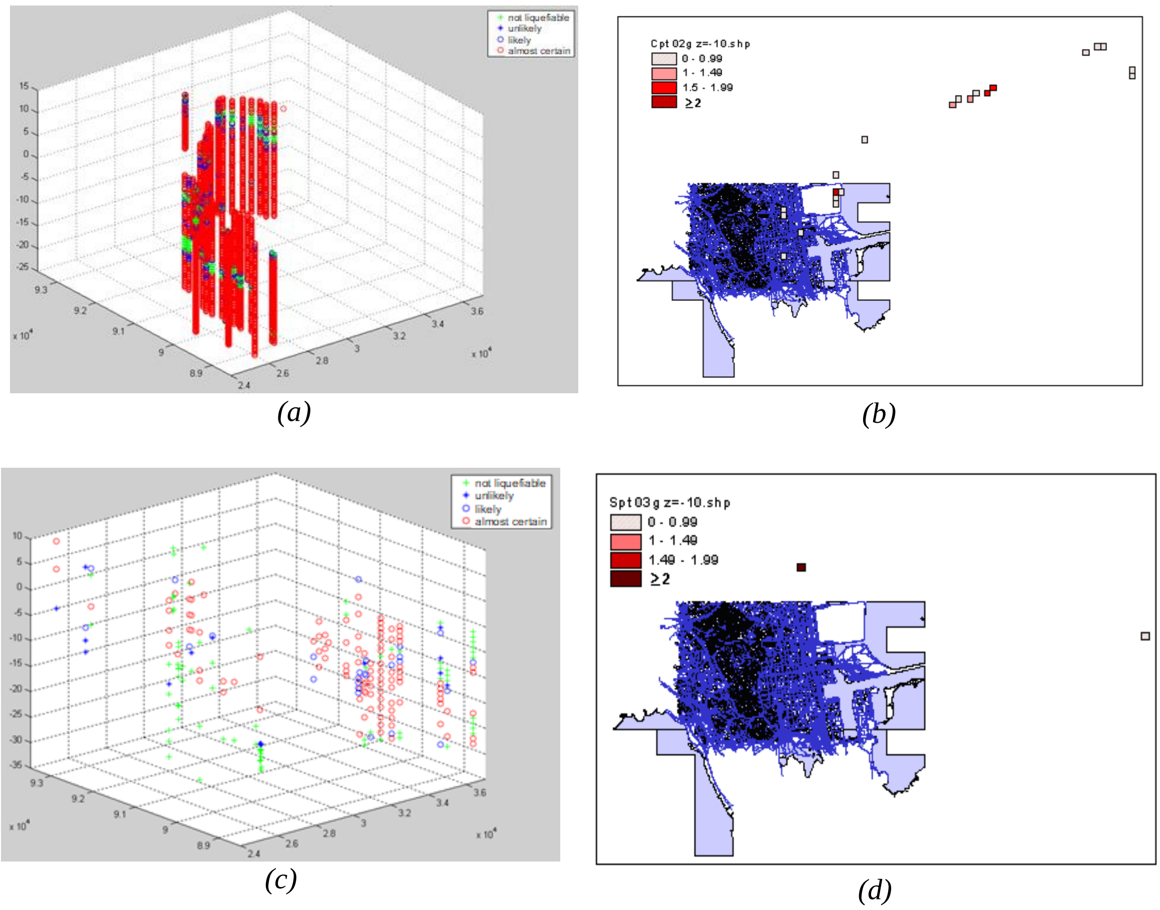
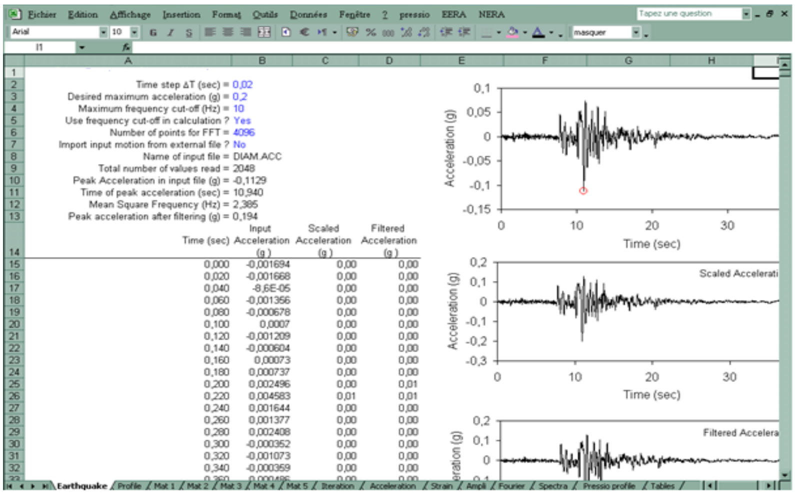


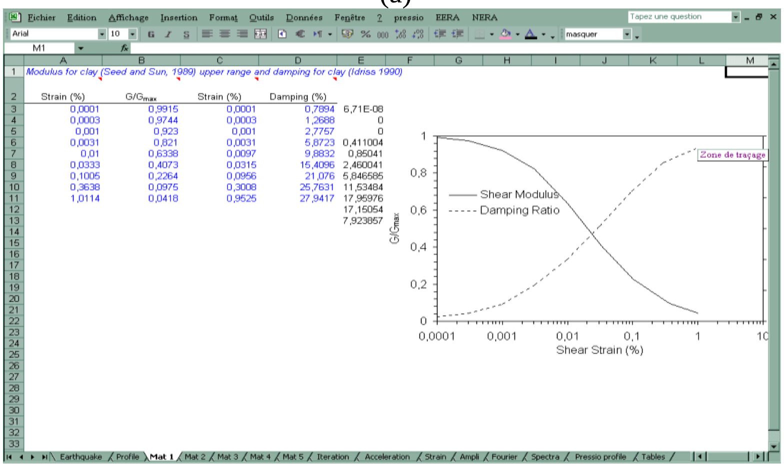

**Fig. 4:** Risk of liquefaction estimated according to the CPT and SPT test: (a) Risk according to the CPT test spatially in 3D; (b) Risk according to the CPT test at depth z = -10m; (c) Risk according to the SPT test spatially in 3D; (d) Risk according to the SPT test at depth z = -10m

The cyclic shear stress induced by seismic loading is calculated, on some characteristic stratigraphic profiles, by dynamic wave propagation calculations. We begin by introducing the characteristics of the study earthquake and the value of the acceleration of setting (Figure.5.a).

We chose the characteristic profile corresponding to the studied site (pressuremeter test SP5 as an example). We introduced the value of the limit pressure with the corresponding depths as well as the characteristics of the existing layers: materials, thicknesses, and density of the soil. EERA software calculates soil profile characteristics as well as material characteristics from the introduced pressuremeter profile (Figures.5.b).




(a)

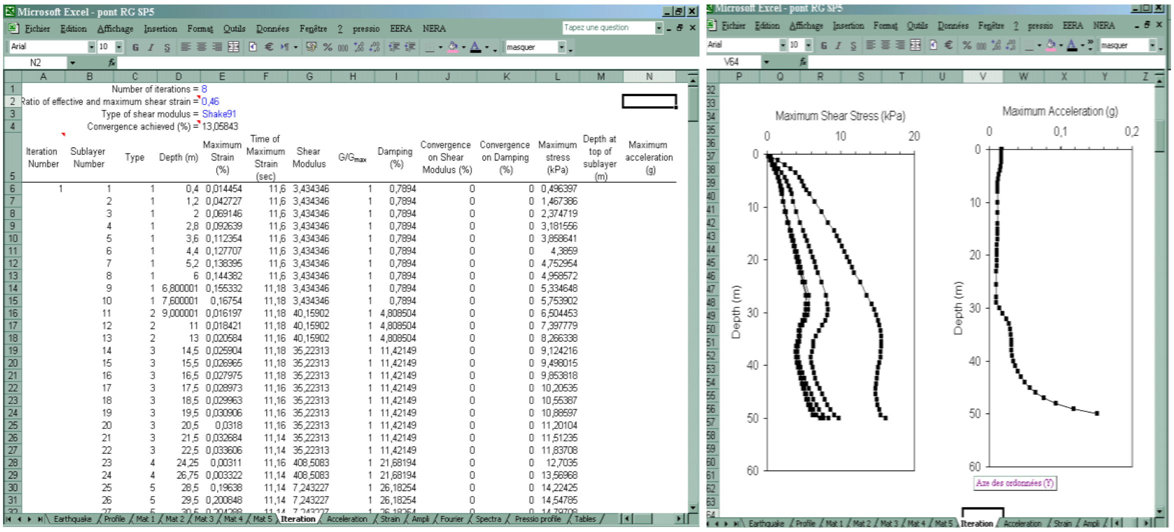



(b)

**Fig. 5:** characterization of the study site by EERA software: (a) Characteristics of the study earthquake; (b) Characteristics of materials

Once the soil profile and study earthquake characteristics are established, we proceed to the computation of the constraints by the EERA Iteration menu (figures.6).

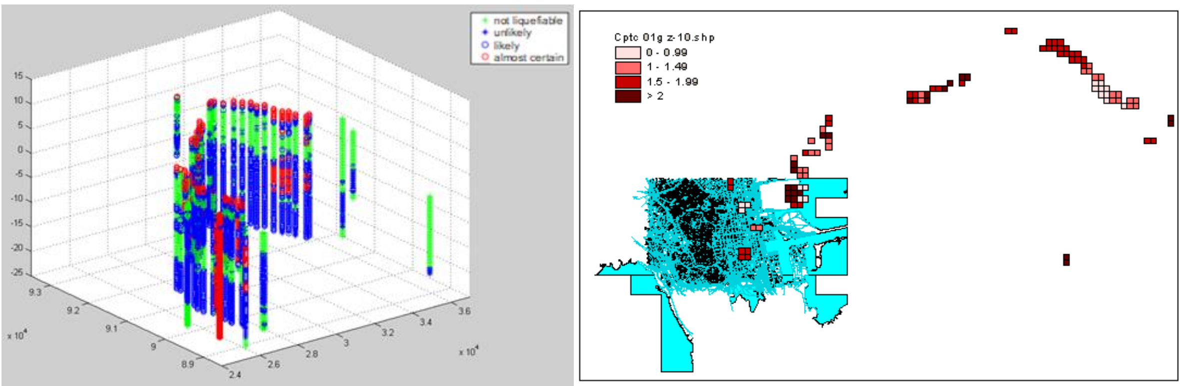
Once the value of the equivalent linear stress is obtained, the same calculations are repeated at level B; we introduced the maximum shear stress values into the Exel worksheet for each soil depth and recalculated the safety factor values.




(a) (b)

**Fig. 6:** computation of the constraints by the EERA Iteration: (a) Calculation of stresses in a soil profile; (b) Variation of maximum shear stress versus depth and amax value after convergence

The risk of liquefaction at this level C was identified by simultaneously basing on the results of the CPT and SPT tests; the results are presented, as in the studies of previous levels, by means of 3D spatial representations and sections at different depths (z = 0, -5, -10, -15, and -20m). Some examples (amax = 0.1g) of significant representations of these results are given below (Figure.7).




(a) (*b*)

**Fig. 7:** Liquefaction Risk estimated according to the CPT test (for amax = 0.1g): (a) spatially in 3D; (b) at depth z = -10m

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