Naama Sukenik, David Iluz, Orit Shamir, Alexander Varvak and Zohar Amar

Purple-Dyed Textiles From Wadi Murabba'at

Historical, Archaeological and Chemical Aspects

Abstract
This article presents three prestigious textiles dyed with murex shellfish, which were found in the Murabba'at Caves in the Judean Desert and are dated to the Roman Period. The textiles were analyzed using High Performance Liquid Chromatography (HPLC). The results of the analysis indicate that one textile was dyed using Hexaplex trunculus *and its color tends to blue-greenish; apparently, the dye solution was exposed to the sun during the dyeing process. The other two textiles underwent a double dyeing process using the* Hexaplex trunculus *and the Armenian Cochineal insect dye in order to give the fabric a reddish purple color, which was indicative of high status. Such a combination has not been reported in the results of dye analysis of ancient Israel textiles. Furthermore, these finds are unusual and unique in light of discoveries of other textiles from Israel dated to the Roman Period. According to the dye analysis and tests of different aspects of the purple textiles, we propose the origin of the textiles.*

Key words: *Royal purple,* Hexaplex trunculus*, Armenian Cochineal, HPLC, Dyes, Murabba'at Caves.*

Introduction

The Royal purple dye is a reddish-purple natural dye which was the most prestigious of all dyes used in the ancient world. The true Royal purple was produced primarily from three species of sea mollusks of the *Muricidae* family, which were common in the Mediterranean Sea: *Hexaplex trunculus (Murex trunculus), Bolinus brandaris (Murex brandaris)* and *Stramonita haemastoma (Thais haemastoma)*. Although the use of murex mollusks for dye began in Early Bronze Age (Stieglitz 1994, 46-54), it appears that during the Hellenistic and Roman periods, the popularity of purple dye grew as never before. In the 3rd and the 4th centuries CE, this tendency became stronger after an edict was issued prohibiting the public from wearing purple, thereby making it exclusive to the Emperor and his family. This prohibition made the purple dye even more popular among the public.

The process of producing dyes from murex mollusks is more complex than the process required for producing dyes from plants. The murex fisher must have the appropriate skill and a close familiarity with the different species of mollusks. The dye substance in the murex mollusks comes from the hypobranchial gland located under the mollusk's mantle (Spanier and Karmon 1987), and therefore it is necessary to remove the gland from the mollusk. This is accomplished by cracking the shell, an action requiring much physical effort, accuracy and proficiency (Amar 2013, 115-120). Moreover, Royal purple belongs to the class of vat dyes, dyestuffs which must be reduced to soluble leuco form before they can be used for dyeing (Koren 1996). Vat dying involves biochemical and photochemical reactions and complex reduction and oxidation processes, which would have taken a number of days in ancient times and required the inclusion of additional materials (Karmon 1993, 36; Cooksey 2001, 737-738). It was only after many attempts and experiments that this complex process was successfully reconstructed (Edmonds 2002; Kanold 2005; Koren 2005).

Researches have previously noted excessive amounts of murex needed for dyeing (Friedlander 1909, 766);

this craft obviously required large quantities of mollusks. According to new research one mollusk has only 1.5 g dye on average and in order to dye 3 kg of wool, it is necessary to use 1000 mollusks (Amar 2013, 122). This is probably the reason that true purple was usually used only in decorative elements requiring small amount of dyed wool.

Furthermore, unlike other dyes, the final color depends on exposure to light and demanded a high level of expertise, resulting in a range between shades of bluish purple when the dye solution is exposed to sunlight and reddish purple when the dye is not exposed to sunlight (Elsner and Spanier 1985, 126). Vitruvius, who observed this phenomenon, wrote in his book that the color of purple "does not yield the same colour everywhere, but is modified naturally by the course of the sun" (*De Arcitectura*, VII, 13.1). Similarly most researchers agree that the two prestigious colors in the Bible, *Argaman* (reddish purple color) and *Tekhelet* (bluish purple color) derived from the *Hexaplex trunculus* species (eg. Exodus 26: 1; Elsner and Spanier 1985, 125-126; Ziderman 2008). The attributes of this dye are also reflected in it being color-fast after washing and exposure to the sun. Plutarch (45-120 CE) noted that among the treasures of the Persian kings, Alexander found purple cloth which had not faded although it had been dyed 180 years earlier (Plutarch, *Lives*, XXXVI, 1). The beauty of the color on the one hand, and the difficulty in obtaining and using it on the other hand, were reasons that made it the most expensive of all of the dyes.

Many of the natural historians devoted considerable attention to purple, among them: Pliny (*Naturalis Historia*, VI, 201; IX, 125-142; XXXV, 44-45), Vitruvius (*De Arcitectura*, VII, 13.1) and Aristotle (*Historia Animalium*, V. 15). Compared with the many literary sources, there are far fewer archaeological traces of the purple dye industry. Accumulations of crushed murex shells found along the seacoast represent indirect evidence of the purple dye industry that flourished along the Mediterranean Sea shore (Karmon and Spanier, 1987, 147-158; Reese 2010, 113-141). Other archaeological finds are stains of purple pigment in the inner surface of jars associated with the purple dye industry and identified by means of analytical instrumentation as 'Royal purple' (Karmon and Spanier 1987, 151-155; 1988, 185; Koren 2008).

Other important evidence for the use of true purple can be found in archaeological textiles. Purple-dyed textiles are few and were found on sites that were generally located along important commercial routes, such as Palmyra (Pfister 1934, nos. L.12, T.10, T.11, T.12; 1940: nos. T.84, T.85, T.86, T.87, T.91) and Dura Europos in Syria (Pfister and Bellinger 1945, nos. 57, 58, 61). Prior to the present study, only two textiles found in Israel were identified as dyed with Royal purple. They have been found at Masada and are dated to the Herodian period (37-4 BCE). One of these textiles is blue and the other purple (Koren 1997, 23-24; Kraft 2011). Recently, in a comprehensive study conducted on the textiles found in the Judean Desert in order to identify dyes, 180 samples of textiles were analyzed. These selected textiles came from the Cave of Letters, the Cave at Nahal Hever, the Christmas Cave, the Pool Cave and the Murabba'at Caves (Sukenik 2013). In this article the dye analysis of three textiles from the Murabba'at Caves is presented. The three textiles are stored at the Israel Antiquities Authority.

Textiles from the Murabba'at Caves

Wadi Murabba'at is a deep ravine descending from the Judean Desert towards the Dead Sea (a descent of 200 meters), some 18 kilometers south of Qumran. Along the wadi, five caves were discovered. These caves were excavated by Harding, de Vaux and Barthélémy at the beginning of 1952, following the discovery of written documents by the Bedouins (de Vaux 1961, 3-8). The archaeological artifacts that were recovered in the caves were dated to the Chalcolithic Period, the Middle Bronze Age, the Roman Period, the early Islamic Period, as well as more recent times, but the largest bulk of the material is dated to the Chalcolithic and Roman Periods (de Vaux 1961, 10-13). The caves are known primarily for the many documents that were found inside them. These documents had been brought to the site during the Bar Kokhba Revolt (waged between 132-135/136 CE by the Jews of the southern Levant against the Roman Empire). Among these documents one was of supreme importance to academic research, as it stated the full name of Bar Kokhba who was the leader of the revolt (Milik 1961, 122-134).

Among the finds were 109 textiles from various periods. Some of these textiles were examined and catalogued by Grace and Elizabeth Crowfoot (Crowfoot and Crowfoot 1961). Some of the linen textiles were dated to the Chalcolithic period, while a smaller group in linen, cotton and silk were dated to the medieval times, and 86 of the textiles dated to the Roman Period. Of these 17 were of linen, one of goat-hair, and 68 were of wool (Crowfoot and Crowfoot 1961, 54-60; Shamir 2006, 85). Dyed textiles are all made of wool, and the possibility that some of the dyed textiles could be dated to the Chalcolithic Period is ruled out because at that time, only linen was used for weaving textiles in the area (Schick 2002, 238; Shamir 2013b). Furthermore, Crowfoot and Crowfoot dated the dyed textiles to the days of the Bar Kokhba Revolt based on

Fig. 1. Textile no. 12 from Murabba'at Caves (Photo: Clara Amit, courtesy of the Israel Antiquities Authority).

Fig. 2. Textile no. 20 from Murabba'at Caves (Photo: Clara Amit, courtesy of the Israel Antiquities Authority).

Fig. 3. Textile no. 22 from Murabba'at Caves (Photo: Clara Amit, courtesy of the Israel Antiquities Authority).

the archaeological context (Crowfoot and Crowfoot 1961, 51). On some of the textiles, vertical woven-in bands (*clavi*), in various shades of red, brown, purple, blue and green were found, a decoration characteristic of the Roman Period tunic (Bender Jørgensen 2011; Shamir 2013).

The textiles

The three textiles from the Murabba'at caves chosen for dye analysis are all fragmentary and were originally part of larger textiles. Textiles nos 12 (IAA No. 490063, Fig. 1) and 20 (IAA No. 490070, Fig. 2) are decorated with *clavi* in a reddish purple colour but only part of the bands are preserved. Warp and weft in both textiles are made of z-twisted yarns. The ground weave in Textile no. 20 is plain weave while it is it not preserved in the other textile. The warp threads are made of undyed wool yarns. The bands are weft-faced with approximately 80 weft threads/cm, and wefts completely cover the warps threads. In order to achieve this effect the warp threads are grouped in the band. This phenomenon is typical of the Roman period (Bender Jørgensen 2011, 78) and was also documented in textiles from sites such as `En Rahel (Shamir 1999, 94) and Masada (Sheffer and Granger-Taylor 1994, 198-199).

Textile no. 22 (IAA No. 490073, Fig. 3) is decorated with stripes in a greenish-blue colour, which probably originally have been blue, mixed with narrow brown and cream coloured stripes. The textile is a warp-faced tabby. The warp is made of plied yarns, S2Z with 25 threads/cm, while the weft is made of single s-twisted yarns with a thread count of 7 threads/cm. The textile has three coarse sewing threads inserted into the weave, indicating secondary use.

Dye identification

In the course of the study, the textiles were analyzed by HPLC (High-Performance Liquid Chromatography). The samples were tested several times, according to a number of parameters and under identical conditions (for a detailed description of this method, see Sukenik 2013, 165-167; for parallel studies Koren 2006, 47-48), and they were compared to samples of modern wool that we dyed with shellfish purple experimentally. In the course of the analysis, we identified the various components of the dye sample and determined the source of the dye at the level of species.

The major dye component that were detected in extracts from Textile no. 22 was indigotin (IND), which is found in plant sources such as woad (*Isatis tinctoria L.*) and the indigo plant (*Indigofera tinctoria L*), but also in several species of shellfish (Koren 2006; Clark *et al*. 1993) (Fig. 4). In addition, two more substances were found which exist only in mollusk dyes: 6`-monobromoindigotin (MBI) and 6,6`-dibromoindigotin (DBI) (Wouters and Verhecken 1991, 269, Fig. 4) Therefore, it can be determined with certainty that the textile was dyed with genuine shellfish dye. Moreover, although the results of the analysis are affected by many factors such as the sex and age of the mollusks, geographic location, the dyeing process and the method of the analysis (Koren 2008, 388-389), it may be established based on the percentages of the substances identified, that the origin of the purple color that was used in this textile was *Hexaplex trunculus.* According to the chromatogram, the percentage of IND and MBI material was high, and this is characteristic particularly of *Hexaplex trunculus*, in contrast to *Bolinus brandaris* and *Stramonita haemastoma* in which the concentration of IND is low

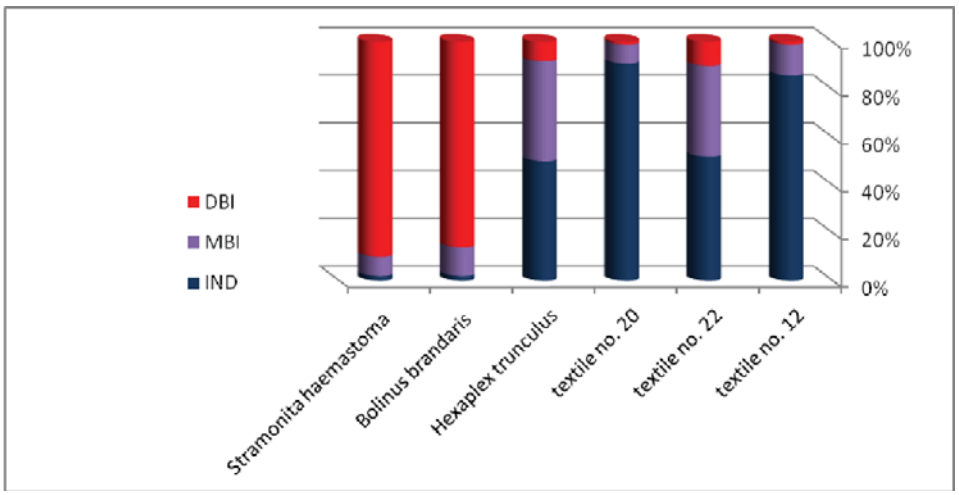

Fig. 4. Relative presence of dyes components at 554 nm of archaeological textiles compared with modern textiles dyeing with three species of sea mollusks.

and the concentration of DBI is high (Koren 2013, 32; Michel et al. 1992, 147, Fig. 4). A similar profile is also seen in textiles no. 12 and no. 20 and thus it can be determined that they, too, were coloured with dye substance obtained from *Hexaplex trunculus*.

At the same time, analysis of Textiles nos 12 and 20 detected the presence of an additional component, Carminic acid, which is found in various species of insects (*Coccidae spp.*), which were known to the dyeing industry in antiquity. It can be determined with certainty that the source is not the Oak Kermes (*Kermes vermilio and K. echinatus*) that was known to be used in the Middle East region, because this kermes does not contain any Carminic acid (Wouters and Verhecken 1989, 192; Amar et al. 2005, 782). It can further be established with certainty that this is not the American Cochineal (*Dactylopius coccus*), despite the high concentration of Carminic acid in it, because this insect belongs to the New World and was originally endemic to Central and South America (Cardon 2007, 619-632). Carminic acid is the principle component found in the Armenian Cochineal (*Porphyrophora hamelii*), in contrast to the Polish Cochineal (*Porphyrophora polonica*), which also contains kermesic acid in a significant quantity (Wouters and Verhecken 1989, 193). Most of the researchers date the use of the Polish Cochineal to the 6th or 9th century CE (Forbes 1964, 102; Cardon 2007, 644), and as this is considerably later than the dating of the textiles examined here, the use of the Polish Cochineal as a dye substance in this context can be excluded.

Discussion

Based on the chemical analysis that was conducted on the textiles in order to identify the dyes, it appears that the three textiles from Murabba'at were dyed with *Hexaplex trunculus* sea mollusk. One textile was dyed using *Hexaplex trunculus* and its color tends to be blue-greenish, and so it seems that during the dyeing process, the dye solution was exposed to sunlight to produce the blue color (by photodebromination of the reduced leuco-dye; Elsner and Spanier 1985) or heated after having been dyed to produce this color. The importance of this textile is extremely significant as there are practically no parallels for it in the archaeological record. As mentioned above one blue-purple textiles was found in Massada but published only in conferences and press (Kraft 2011). Other textile in the Katoen Natie Collection in Belgium, have only blue fibers which produced from Murex snail (Koren 2013, 31). In burial in Pazyryk at Siberia blue textile was found (Sterman and Sterman 2012, 44-47). The other two textiles underwent a double dyeing process, using *Hexaplex trunculus* and Armenian Cochineal in order to give the textile a reddish purple color. These results are interesting in light of the dye analyses conducted by Sukenik on the Judea Desert Cave textiles. Out of the 180 tests conducted on the wool textiles from the Roman Period, no other textiles contained dyes from animal sources such as sea mollusks and insects (Sukenik 2013). In all other instances the purple shade was obtained with dyes from plant sources and using the 'double-dye' technique, i.e., double dipping wool in two separate dye solutions in order to produce a new hue. First the wool was dipped in a solution of madder (*Rubia tinctorum L.*) which gave a red color, then it was dipped in an indigotin containing dye bath, based on woad (*Isatis tinctoria L.*) or the indigo plant (*Indigofera tinctoria L.),* in order to imitate the purple color at a low cost (Cardon et al. 2011, 199-200). The use of this technique, as well as the absence of true purple in the majority of textiles examined, are compatible with other sites in Israel from the Roman period (except Masada) such as En Rahel (Koren 1999), Mo`a (Sukenik et al. forthcoming), and Wadi ed-Dâliyeh (Whiting and Sugiura, 1974). A new research suggests that wearing true purple textiles was more accessible to the middle and lower classes than previously thought (Cardon et al. 2011, 197-214). From our results, it appears that true purple textiles were not commonly used in Israel of the Roman period, and the discovery of purple-dyed textiles from Wadi Murabba'at is unusual and perhaps unique.

Dyeing techniques according to literary sources

Literary sources indicate that the purple colour was not limited to one specific hue. According to Pliny the Elder, the fashion in hues of purple ranged from shades of bluish purple to reddish purple, and Pliny the Elder used different words to describe the various hues: *violacea* and *purpura* for bluish purple, and *rubra* to indicate a reddish purple colour (*Naturalis Historia* IX, 137). It seems that, in antiquity, people took advantage not only of the dye's property of changing color in response to exposure to sunlight (see above), but they also used to dip the purple fleece in additional dye solutions to give it a new and unique color. 'Double dyeing' was a common technique used in the dyeing industry to imitate prestigious dyes. With this technique it was possible to change the shade of purple obtained only from shellfish and to produce a reddish purple by dipping it a second time in a red solution produced from the madder plant (*Rubia tinctorum L.)* or from the Coccid scale insect (*Coccidae spp.*). The technique required great skill and precision and was carried out by professional craftspeople who were expert in the art of dyeing, which most likely made the cost of the finished garment higher.

Pliny the Elder mentions two different colors produced by the double dyeing technique and each was given a different name. Tyrian purple, whose color resembled wine or clotted blood (*Naturalis Historia* IX, 135), was the most prestigious of these dyes. According to Pliny's description, Tyrian purple was made by using two species of muricid mollusks, and it cost ten times as much as a textile dyed with only one species (*Naturalis Historia* IX, 137). The other dye of similar color was called *Hysgine* and was obtained by using the shellfish and various insects dyes (*Naturalis Historia* IX, 141).

Shellfish Purple and Insect Dyes

Using insects as a source for the high-status scarlet dye was known from earlier times, and it is accepted that this is the color referred to in Jewish sources as '*Tola'at sha-hani*' (Amar et al. 2005), which appears in the Bible many times along with *'Argaman'* (e.g.: Exodus 36: 35). The dye is produced from several types of scale insects (*Coccidae spp.*), which live as parasites on various plants. The dye is collected from the body of the females and the eggs they contain. They must be harvested within a short period lasting less than a month and requires skill and experience. The Armenian Cochineal (*Porphyrophora hamelii*) is not native to Israel but is found on the roots of grass plants (*Gramineae*) in the Mountains of Ararat in Turkey and Armenia (Donkin 1977, 849-853; Cardon 2007, 646-652). The difficulty in identifying the insects on the plants and the short period of time during which it must be harvested, in addition to the beautiful red hue produced by it, made this dye one of the most sought after of the red dyes, and Pliny listed it among the three most important dyes in the industry (*Naturalis Historia* XXI, 45-46).

Reddish purple colors obtained by using the 'double dyeing' technique is known in a number of other textiles dated to the Roman Period. Pfister who examined the Palmyra textiles found textiles which were double dyed with murex and an insect dye which he identified as Persian Cochineal (*Cochenille de Perse*; Pfister 1934, nos. T.18, T.19). In an additional report published in 1940, Pfister re-identified the dye as Polish Cochineal (Pfister 1940). The re-examination of the textiles established that the insect dye was in fact Armenian Cochineal (Böhmer and Karadag 2003, 92). Furthermore, at the Maximianon site in eastern Egypt a textile was found dated to the Roman Period, which was dyed with Kermes and *Hexaplex trunculus* (Wouters et al. 2008, 13, textile no. 95.33039.9) and two other textiles came from Didymoi – another Roman fortresses on the road to Berenike (Cardon et al. 2011, 202-203). It may be assumed that this technique of dyeing was used widely for apparel worn by the upper classes and indicates the popularity of the reddish purple shade.

Textile Origin

Based on the identification of the dyes, it may be suggested that Textile No. 12 and Textile No. 20 from Murabba'at are imported textiles. That is because they were dyed with the Armenian Cochineal, an insect that was not prevalent in the southern Levant. Furthermore, this premise is consistent with the technical aspect of the textile, since both warp and weft are z-spun, a manner of spinning that is very rare in Israel and Egypt. An examination of thousands of textiles throughout this region that was carried out by Shamir revealed that most of the textiles from the Roman period are s-spun and the few that are z-spun in both warp and weft are considered to be imported (Shamir 2006, 210-212). The high-quality weave, the fineness of the textile in addition to the dyeing technique used suggest that both textiles were imports. On the other hand, we believe that Textile no. 22 was probably locally made, because the warp and the weft threads are s-spun, which is typical of the southern Levant. Furthermore, the textile is crude (the weft threads are very thick). Moreover, it was dyed only with *Hexaplex trunculus* which is common in the Mediterranean Sea.

It is difficult to determine the identity of the owners of these luxury textiles and how the later found their way to the Murabba'at Caves in the Judean Desert. However, several suggestions may be cautiously proposed:

1) The textiles were the property of the refugees from the Bar Kokhba Revolt even before they reached the Murabba'at Caves, while they were still living a life of affluence and enjoying the benefits of foreign trade. According to Eshel and Amit (1998, 14), the refugees who reached the caves included the commanders and leaders of the administrative and military center of the revolt and therefore they probably owned valuable property, including imported textiles. Similarly, luxury items such as glass utensils and metal appliances were found in the Cave of Letters (Yadin 1963, 42-110).

2) The textiles represent part of the spoils that the rebels took during the Bar Kokhba Revolt and so do not necessarily attest to the economic status of the cave inhabitants.

3) In our opinion, the most probable explanation is that the textiles may not have belonged to the same group of refugees who sought shelter in the caves, but were the property of a military unit that was stationed in the Murabba'at Caves after the Bar Kokhba Revolt. According to the excavation team, finds indicate that a small Roman military unit was deployed in the caves

after the suppression of the Bar Kokhba Revolt (this is unlike the case of the Cave of the Letters, in which no evidence was found of the presence of a Roman military unit). This is based primarily on the documents found on the site that are attributed to the soldiers who served in the 10th Legion (Benoit 1961, 240-243; Popvić 2012, 558). In a number of wall-paintings that were found in various locations such as Brigetio in Hungary and Dura Europos in Syria, and are attributed to Roman military units, figures depicted wear tunics which are decorated with a reddish purple *clavi* (Sumner 2009, 137-138; Pásztókai-Szeőke and Paetz gen. Schieck, in press). Similarly, at the Maximianon site and Didymoi in Eastern Egypt, which served as a military fortresses for protecting the roads (Wouters et al. 2008, 1; Cardon et al. 2011), purple textiles were found, the dyeing process of which is similar to that of the textiles discussed here. Accordingly, it is possible that senior officers had the resources to purchase such valuable clothing (Sumner 2009, 116). We note that the textiles found in the Cave of Letters did not include textiles that had been dyed with true purple (Abrahams and Edelstein 1963, 270-279; Sukenik 2013, 232-234, who inspected 126 textiles from the Cave of Letters). It is possible that this is due to the presence of the military unit at Murabba'at caves.

Conclusion

Yadin, referring to the report on the textiles in the Murabba'at Caves published by Crowfoot and Crowfoot, commented: "Only one important factor – in our opinion – was neglected: the dyes were not analyzed" (Yadin 1963, 170, note 10). In the present study, an attempt was made to complete the task, and the results of the dye analyses on the textiles of the Murabba'at Caves expand our understanding of the purple dye use. It appears that this discovery from the Murabba'at Caves is indicative of the influence of Roman culture on the local population in the southern Levant. These precious textiles symbolize the economic and social status of the upper class and were eagerly sought after by people from various social strata at that time. Apparently, evidence of what Pliny the Elder called *purpurae insania* (*Historia Naturalis* IX, 127) or "the mad lust for purple" survived not only in his writings but is also reflected in the archaeological finds.

Acknowledgements

We are grateful to Koschitzky Foundation and the Department of Land of Israel Studies and Archaeology at Bar-Ilan University for funding the translation of this article and to Hero Granger-Taylor who helped with the examination of Textile No. 22.

Bibliography

Abrahams, D. H. and Edelstein, S. M. (1963) Appendix. A Study of the Textiles from the Color Standpoint. In Y. Yadin (ed.), *The Finds from the Bar Kokhba Period in the Cave of Letters*, 270-279. The Israel Exploration Society. Jerusalem.

Amar, Z., Gottlieb, H., Varshavsky, L. and Iluz, D. (2005) The Scarlet Dye of the Holy Land. *Bioscience* 55(12), 1080-1083.

Amar, Z. (2013) A Brief Guide to Crimson-Production Snails. *'Al 'Atar* 17, 111-123 (in Hebrew).

Bender Jørgensen, L. (2011) Clavi and non-clavi: Definitions of various bands on Roman textiles. In C. Alfaro, J. P. Brun, P. Borgard and R. Pierobon Benoit (eds), *Purpureae Vestes III. Textile y Tintes en la ciudad antiqua. Actas del III Symposium Internacional sobre Textiles y Tintes del Mediterráneo en el mundo antiguo.* 75-81. Napoles.

Benoit, P. (1961) Textes Grecs et Latins. In P. Benoit, J.T. Milik and R. de Vaux (eds), *Les Grottes de Murabba`ât,* Discoveries of the Judaean Desert 2, 209-290. Oxford.

Böhmer, H. and Karadag, R. (2003) New Dye Research on Palmyra Textiles. *Dyes in History and Archaeology* 19, 88-92.

Cardon, D. (2007) *Natural Dyes, Sources, Tradition, Technology and Science*. London.

Cardon, D., Nowik, W., Granger-Taylor H., Marcinowska, R., Kusyk, K. and Trojanowicz, M. (2011) Who Could Wear True Purple in Roman Egypt? Technical and Social Considerations on Some New Identifications of Purple from Marine Molluscs in Archaeological Textiles. In C. Alfaro, J.-P. Brun, PH. Borgard, R. Pierobon Benoît (eds) *Textiles y Tintes del Mediterráneo en el mundo antiguo*. 197-214. Universitat de València - Centre Jean Bérard.

Clark, R. J. H. Cooksey, C. J. Daniels, M. A. M. Withnall, R. (1993) Indigo, woad, and Tyrian Purple: important vat dyes from antiquity to the present. *Endeavour* 17 (4), 191-199.

Cooksey, C. J. (2001) Tyrian Purple: 6,6`-Dibromoindigotin and Related Compounds. *Molecules* 6, 736-759.

Crowfoot, G. M. and Crowfoot, E. (1961) The Textiles and Basketry. In P. Benoit, J. T. Milik and R. de Vaox (eds), *Les Grottes de Murabba`ât, Discoveries in the Judaean Desert* 2. 51-63. Oxford.

Donkin, R.A. (1977) The Insect Dyes of Western and West Central Asia. *Anthropos* 72, 847- 880.

Edmonds, J. (2002) The Mystery of Imperial Purple Dye. *Historic Dyes Series* 7, 1-38.

Elsner, O. and Spanier, E. (1985) The Dyeing with Murex Extracts, An Unusual Dyeing Method of Wool to the Biblical Sky Blue. *Proceeding of the 7th International Wool Textile Research Conference* 5, 118-130.

Eshel, H. and Amit, D. (1998) The Nature of the Refuge Caves in the Judean Desert. In H. Eshel and D. Amit (eds), *Refuge Caves of the Bar Kokhba Revolt*, 13-21. Tel-Aviv. (in Hebrew).

Friedlander, P. (1909) Uber den Farbstoff des antiken Purpurs aus murex brandaris, *Berichte der Deutschen Chemische Gesellschaft* 42/1 765-770.

Forbes, R. J. (1964) *Studies in Ancient Technology*, 4. Leiden.

Kanold, B. I. (2005) The Purple Fermentation Vat: Dyeing or Painting Parchment with Murex trunculus. *Dyes History and Archaeology* 20, 150-154.

Karmon, N. and Spanier, E. (1987) Archaeological Evidence of the Purple Dye Industry from Israel. In E. Spanier (ed.), *The Royal Purple and the Biblical Blue Argaman and Tekhelet*, 147-158. Jerusalem.

Karmon, N. and Spanier, E. (1988) Remains of a Purple Dye Industry Found at Tel Shiqmona. *Israel Exploration Journal* 38, 184-186.

Karmon, N. (1993) The Purple Dye Industry in Antiquity. In C. Sorek and E. Ayalon (eds.), *Colors from Nature: Natural Colors in Ancient Time*, 35*- 37*. Tel Aviv.

Koren, Z. C. (1996) Historico-Chemical Analysis of Plant Dyestuffs Use in Textiles from Ancient Israel. In M. V. Orna (ed.), *Archaeological Chemistry Organic, inorganic, and Biochemical Analysis*, 269-310. Washington, DC: American Chemical Society Symposium Series 625.

Koren, Z. C. (1997) The Unprecedented Discovery of the Royal Purple Dye on the Two Thousand Year-Old Royal Masada Textile. *The Textile Specialty Group Postprints* 7, 23-34.

Koren, Z.C. (1999) Microscopic and Chromatographic Analysis of Decorative Band Color on Nabatean 'En Rahel Textiles – Kermes and Shaded Band. *Atiqot* 38 129-136.

Koren, Z. C. (2005) The First Optimal All-Murex All-Natural Purple Dyeing in the Eastern Mediterranean in a Millennium and a Half. *Dyes in History and Archaeology* 20, 136-149.

Koren, Z. C. (2006) HPLC-PDA Analysis of Brominated Indirubinoid, Indigoid, and Isatinoid Dyes. In L. Meijer, N. Guyard, L. Skaltsounis and G. Eisenbrand (eds), *Indirubin, the Red Shade of Blue*, 45-53. Roscoff.

Koren, Z. C. (2008) Archaeo-Chemical Analysis of Royal Purple on Darius I Stone Jar. *Microchim Acte*, 162, 381-392.

Koren, Z. C. and Verhecken-Lammens, C. (2013) Microscopic and Chromatographic Analysis of Molluskan Purple Yarns in a Late Roman Period Textile, *e-Preservation Science*, 10, 27-34.

Kraft D. (2011). Rediscovered, Ancient Color is Reclaiming Israeli. *The New York Times* 27.2.2012. http://www.nytimes.com/2011/02/28/world/middleeast/28blue.html

Michel, R. H., Lazar, J. and McGovern, P. E. (1992) The Chemical Composition of the Indigoid Dyes Derived from the Hypobranchial Glandula Secretions of Murex Molluscs. *Journal of the Society of Dyers and Colourists* 108, 145-150.

Milik, J. T. (1961) Textes Hébreux et Araméens. In P. Benoit, J.T. Milik and R. de Vaux (eds), *Les Grottes de Murabba`ât, Discoveries in the Judaean Desert* 2, 67-205. Oxford.

Pásztókai- Szeőke, J. and Paetz gen. Schieck, A. (in press) Power Dressing in Pannonia Tunics with Arrow-Shaped Purple Decoration Depicted in Brigetio. In G. C. Alfaro (ed.), *Political Power and Appearance: Luxury and Dress in the Roman Empire and its Provinces*. Valencia

Pfister, R. (1934) *Textiles de Palmyre*. Paris.

Pfister, R. (1940) *Textiles de Palmyre*. Paris.

Pfister, R. and Bellinger, L. (1945) *The Excavations at Dura Europos Vol IV, part II, The Textiles*, New Haven: Yale University Press.

Popvić, M. (2012) Qumran as Scroll Storehouse in Time of Crisis? A Comparative Perspective on Judaean Desert Manuscript Collection. *Journal for the Study of Judaism* 43, 551-594.

Reese, D. S. (2010) Shells from Sarepta (Labanon) and East Mediterranean Purple-Dye Production. *Mediterranean Archaeology and Archaeometry* 10(1), 113-141.

Schick, T. (2002) The Early Basketry and Textiles from Caves in the Northern Judean Desert. *Atiqot* 41/II, 223-239.

Sheffer, A. and Granger-Taylor, H. (1994) Textiles From Masada - A Preliminary Selection. In Y. Aviram, G. Foerst and E. Netzer (eds), *Masada* 4, *The Yigael Yadin Excavation 1963-1965*, 153-256. Jerusalem.

Shamir, O. (1999). Textiles, Basketry, and Cordage from `En Rahel. *'Atiqot* 38, 91-124.

Shamir, O. (2006) *Textile in the Land of Israel From the Roman Period Till the Early Islamic Period in the Light of the Archaeological Find,* Thesis Submitted for the Degree Doctor of Philosophy, Jerusalem.

Shamir, O. (2013) Dress: Hellenistic and Roman Period. In D. Master (ed.), *Oxford Encyclopedia of the Bible and Archaeolog.* Pp. 328-336. Oxford.

Shamir, O. (forthcoming) Textiles from the Chalcolithic Period in the Southern Levant. *ATR 56*.

Spanier, E. and Karmon, N. (1987) Muricid Snails and the Ancient Dye Industries. In E. Spanier (ed.) *The Royal Purple and the Biblical Blue Argaman and Tekhelet*, 179-192. Jerusalem.

Sterman, B. and Sterman, J. T. (2012) *The Rarest Blue*, Jeruslaem/New York.

Stieglitz, R. R. (1994). The Minoan Origin of Tyrian Purple. *The Biblical Arcaeologist* 57(1), 46-54.

Sukenik, N. (2013) *Dyes in Textiles from the Early Roman Period in the Judean Desert Caves: Chemical, Historical and Archaeological Aspect*, Thesis Submitted for the Degree Doctor of Philosophy, Bar-Ilan University, Ramat-Gan (in Hebrew).

Sukenik N., Amar Z. and Iluz D. (forthcoming) The Textile Dyes from Mo'a.

Sumner, G. (2009) *Roman Military Dress*. Stroud: History Press.

de Vaux, R. (1961) Archéologie. In P. Benoit, J.T. Milik and R. de Vaux (eds) *Les Grottes de Murabba`ât*, Discoveries of the Judaean Desert 2, 3-63. Oxford.

Whiting, M. C. and Sugiura, T. (1974) Additional Study of the Dyes. In P. W. Lapp and N. L. Lapp (eds), *Discoveries in the Wadi Ed-Daliyeh,* The Annual of the American Schools of Oriental Research, 80-81. Cambridge, Mass.

Wouters, J. and Verhecken, A. (1989) The Coccid Insect Dyes: HPLC and Computerized Diode-Array Analysis of Dyed Yarns. *Studies in Conservation* 34, 189-200.

Wouters, J. and Verhecken, A. (1991) High Performance Liquid Chromatography of Blue and Purple Indigoid Natural Dyes. *Journal of the Society of Dyers and Colorists* 107, 266-269.

Wouters, J., Vanden Berghe, I., Richard, G., Breniaux, R. and Cardon, D. (2008) Dye Analysis of Selected Textiles from Three Roman Sites in the Eastern Desert of Egypt: A Hypothesis on the Dyeing Technology in Roman and Coptic Egypt. *Dyes in History and Archaeology* 21, 1-16.

Yadin, Y. (1963) *The Finds from the Bar Kokhba Period in the Cave of Letters*. Jerusalem.

Ziderman, I. (2008) The Biblical Dye *Tekhelet* and its Use in Jewish Textile. *Dyes in History and Archaeology* 28, 36-44.

Authors:
Naama Sukenik: naamas@israntique.org.il
David Iluz: iluzda@gmail.com
Orit Shamir: orit@israntique.org.il
Alexander Varvak: Alexander.Varvak@mail.biu.ac.il
Zohar Amar: amarzoh@gmail.com