A practical guide to producing raw dye from snails for Royal Purple and Biblical Blue: History and reality

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Introduction

Royal purple [*argaman*] is considered the most precious dye in the ancient world.[1] The dye was produced from the hypobranchial gland (located under the gills) of various types of snails from the Murex family (Muricidae). According to an analysis of the writings and the archaeological finding of the many shells found near ancient dye-producing works along the coast of Israel and other areas in the Mediterranean Basin, and based on the biological research on mollusks familiar to us at present – there are three major species of murex from which the dye is surmised to have been produced: 1. Banded Dye-Murex (*Murex trunculus*),[2] also known as Rock Murex; 2. Spiny Dye-Murex (Murex *brandaris*) [3]; and 3. Red-mouthed Rock-shell (Murex haemastoma).[4]

Figure 1: Species of murex found on Israeli coasts (right to left): Spiny Dye-Murex (*Murex brandaris*); Banded Dye-Murex (*Murex trunculus*), and Red-Mouthed Rock-shell (*Murex haemastoma*)
(Photo: Zohar Amar ©)

[1] This article is part of a broader monograph on the subject: Argaman- Purpura and Arg'uan in Jewish sources. The argaman industry has been surveyed many times in the research literature, see e.g., I. Herzog, The Royal Purple and the Biblical Blue, Argaman and Tekhelet, E. Spanier (ed.), Jerusalem, 1987. E. Spanier and Y. Zeiderman, Purple and blue , *Mada* [Science] (26), 4, 1982: 187-184; N. Carmon, The purple dye industry in ancient times, in H. Sorek and A. Ayalon (eds.) The color of nature, Tel Aviv, 1993, 80-95.

[2] Synonyms: Phyllonotus trunculus, Trunculariopsis trunculus, Murex turbinate, Murex .goldi, Muricanthus trunculus, Hexaplex trunculus.

[3] Synonyms: Bolinus brandaris, Hexaplex brandaris. In English: the purple dye murex.

[4] Synonyms: Stramonita haemastoma, Thais haemastoma, Buccinum haemastoma, Purpura haemastoma. Also known in Hebrew as the equivalent.

A description of the murex, the process of catching and cracking them, and afterward the process of producing dye is mentioned in ancient sources, particularly in the classical sources of the Hellene-Roman era. It seems that the most important sources are Aristotle (384-322 BCE) [5] and Pliny the Elder (23-79)[6], who lived at the end of the Second Temple period. There was a tradition of dyeing on the coasts of the land of Israel and Lebanon until the Byzantine period, and it came to a complete end during the ninth century. It continued during the Middle Ages in several regions around the Mediterranean Sea and we surmise that it had already come to an end in the thirteenth century. This is much earlier dating than the general agreement among scholars that the *argaman* dye industry disappeared with the fall of the Byzantine Empire to the Ottomans (1453). Since that time when the use of royal purple had fallen out of use, the knowledge of the various activities that accompanied the process of producing the dye was lost, as was the active tradition of the unique dye-making craft. In modern times, many studies have been conducted in relation to *argaman* from the perspective of history, biology, ecology, and chemistry. In the last generation applied research has taken a stride forward, particularly with regard to dyeing with *tekhelet* – with the production of dye from the Banded Dye-Murex (*Murex trunculus*) in order to dye the tzitzit [Jewish ritual fringes worn by observant Jews]. We would venture that the studies that were conducted on the *argaman* in order to produce dye are not sufficient for the purpose. The attempts made up until the present in our opinion did not yield adequate results of reproducing the *argaman* dye in accordance with the historical descriptions available to us.[7]

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[5] Aristotle, *Historia Animalium* I, A.L. Peck (trans.), London 1965, V 15.
[6] G. Plinius, Naturalis Historia, H. Rackham, and W.H.S. Jones (trans.), London 1989, IX 125-138.
[7] F. Bruin, 'Royal Purple and the Dye Industries of the Mycenaeans and Phoenicians', in: F. Sarruf and S. Tamim (eds.), *American University of Beirut Festival Book*, Beirut 1967, p. 295-325; J. Doumet, *A Study on the Ancient Purple Colour*, Beirut 1980; Bruin, ibid, pp. 295-325; R.H. Michel and P.E. McGovern, 'The Chemical Processing of Royal Purple Dye: Ancient Descriptions as Elucidated by Modern Science, Part I',. *Archeomaterials* 1, 1987, pp. 135-143; Part II, 4, 1990, pp. 97-104; J. Edmonds, Tyrian or Imperial purple dye, *Historic Dye Series No 7,* 2000; Z. C. Koren, "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, London 2005, pp. 136-149.

Figure 2: Fringes dyed tekhelet, plaited according to Maimonides' method. Dyed using Banded Dye-Murex (Photo: © Zohar Amar)

According to our theory, there is a close connection between *tekhelet* and *argaman*, at least in some of the commentaries which posit that these dyes were produced from the same type of Murex of different species, or alternately, our research has shown that specific species can produce different colors. This of, course, depends on the various conditions of production and different interpretations that were given, for example, to the color known as *tekhelet* (various hues of blue, purple, and green).[8] Because of the aforementioned lack of practical experience in producing dye from the Banded Dye murex and the Red-mouthed Rock-shell, we sought to investigate the subject with the aim of trying to produce argaman dye, that is, a reddish-burgundy shade like the color of clotted blood[9] or the color of wine, [10] as the sources state. It should be noted that in the absence of an uninterrupted, living tradition of dyeing with murex, modern research deals only with re-enactments based on the commentary of historical sources, some of which are unclear or incomplete.

[8] Z. Amar, The Color of Tekhelet according to Maimonides", Hama'yan, 52/2 (2011), pp. 77-87.
[9] According to Pliny, IX 135.
[10] Breshit Rabati, Vayehi 49, 11-12, H. Albeck Edition, Jerusalem 1950, p. 239, and in Targum Onkelos ad loc.

Figure 3: Various hues produced from Banded Dye-Murex: (top) purple under normal lighting conditions. (below) blue, under various conditions of exposure to sunlight
(Photo: Shahar Cohen ©)

Applied Research

The aim of this survey is to offer practical information that was acquired during my trips abroad in order to produce the raw material for research on *argaman*. In the course of this activity, material was extracted from 11,000 murex (4500 Banded Dye Murex and 6500 Murex brandaris, and 50 Spiny Dye-Murex).[11] In this article we will list the sources of the snails used for research, their price, how they were brought and preserved, how they were opened, and how the dye glands were removed and dried. These are essential stages of work that constitute the basis for research in producing the dye, which is discussed elsewhere. We will also relate here to several aspects which came up during the study and enabled us to explain more clearly the halakhic and historical sources. We will

[11] This activity was carried out in July 2009 in Milan, Italy, in collaboration with Dr. Ofer Almalem, for Machon HaMikdash; a second time in July 2011; and a third time, in Sicily in February 2012. I would like to thank my mother -in-law Julianna Ben Zimra and her sister Gabi Franzin who invested much effort in coordinating this activity. Without them this complicated project could not have been carried out. I would also like to think Ms. Evelyn Awat for helping in locating Murex haemastoma among the fishermen of Palermo, Sicily.

furthermore present quantitative data that will make it possible to assess the cost of this process today, and hence to offer a more realistic dimension to the reality of the past.

The source and availability of the snails

According to Israeli law, there is an absolute prohibition against collecting snails from the ocean, and all species are protected by law. For that reason, the raw material for producing *argaman* from murex could be obtained only in countries where mollusks are permitted for commercial purposes such as food. In recent years, raw material has been imported to Israel by the *Petil Tekhelet* association for dyeing tzitzit the color *tekhelet* from Murex brandaris. The source for this material is the coasts of various countries along the Mediterranean Basin: southern Spain, Tunisia, and more recently, Croatia. In contrast, for our research, we produced dried raw material for dyeing from the coasts of Italy. Most of the snail consumption is supplied from the Adriatic Ocean, for example, from Pescara, Chioggia but also from southern Italy and Sicily.

The major source of supply for our research was in the wholesale fish market (Mercato Ittico) in Milan.[12] Although this market is located in an interior city some two hours drive from the ocean, there is an advantage to buying the snails at this commercial center rather than at the port. Buying directly from the fisherman saves the middleman's cost and enables one to obtain snails at a relatively low price. On the other hand, it does not guarantee a regular supply of snails: their availability depends on local conditions of weather, factors such as stormy seas and poor visibility. In general, in the stormy winter months of December-March, there are lower chances of acquiring a large supply of snails. Buying the snails in the fish markets of Milan and Rome enabled us to buy a large variety of fish, crabs, and mollusks, and generally there is no problem when pre-ordering of obtaining murex of the species Banded Dye and Spiny Dye murex in quantities of a few hundred kilograms. But we were unable to acquire for our study snails of the Red-mouth Rock-shell species. Nonetheless, we were able to obtain this type of snail by direct

[12] I would like to thank Dr. Marco Fedol and Dr. Martino Grazioli DVM who allowed me to carry out the research activity in the labs at that site.

supply from the fishermen on the Island of Sicily, who pull them out of the water by hand and not with the nets that we shall presently describe.

Fishing for fish and snails is done today using trawlers with deep-sea nets which scoop them up in great quantities and in a short time, as opposed to the limited fishing techniques used in the ancient world. In the past, murex were also fished with nets. [13] However, at present this system is not selective, picking up in its nets sea creatures of different species. From studies conducted in recent years and from questioning the merchants, it became clear that ecological changes are taking place on the coasts, which are the result of various factors such as increased pollution and in particular, unchecked over-fishing. All of these have led to a drastic decline in the quantity of the daily fishing yield, and there is a real threat of extinction to some species of fish, such as tuna. Thus, as part of managing the fish farming industry, a study was conducted in southern Portugal on the fishing yields of Murex trunculus and Murex brandaris which are an important commercial industry in the local seafood market. The aim is to investigate the possibility of regulating fishing and testing out fishing techniques which will enable sustainable utilization of fish farms in the long term.[14]

It is possible that in the past, too, there was over-fishing that did not allow the population of murex to recover and led to a shortage of them for the dye-making industry, to an increase in price for dyed items of apparel, the nationalization of the industry as a government monopoly, and ultimately, its final decimation. It is possible that the description of the snail as a creature that "emerges from the ocean once in seventy years",[15] (or according to a different version: "once in seven years")[16], symbolizes in

[13] Hunting murex using nets with bait is mentioned by Aristotle (note 5 above) and Aelian, *On the Characteristics of Animals*, London 1959, VII 34. It is also mentioned in the Talmud: "Those who caught the hillazon [snail] tied and untied" (BT, *Shabbat* 74b)
[14] P. Vasconcelos et al., 'The artisanal fishery for muricid gastropods (banded murex and purple dye murex) in the Ria Formosa lagoon (Algarve coast, southern Portugal)', . *Scientia Marina 72* (2), 2008, pp. 287-298.
[15] BT, *Menahot 44a Tzitzit* 1:10. Heiger Edition, p. 52 (in Hebrew)
[16] *Tzitzit* 1:10. Higger Edition, p. 52 (in Hebrew)

hyperbolic terms its scarcity, and this alludes to the fact that in the past there have been sharp fluctuations in the availability of the snails on Israel's shores.[17]

However, the number of consumers of murex for food in Italy is relatively small and marginal, and so at present, there does not seem to be any actual danger of these sources dwindling. Still, the situation requires thinking about their future availability, and therefore it is recommended that the consumers of the *tekhelet* and *argaman* dyes establish a dye bank which would store such raw materials. At this stage, when proposals to breed murex as a cultural industry have been tabled due to the lack of economic feasibility (the cost of raising and feeding them is greater than the cost of buying them), and because of the difficulties arising from their cannibalistic behavior under the crowded terms of captivity,[18] it seems that there is still an advantage in buying the raw material for dye produced from snails which are taken out of the open sea.

Preservation and Storage

The snails taken out of the ocean are packed in bags of nylon netting (made of thin fishermen nets) weighing 3 or 5 kilo. That is a strong packaging that allows maximum ventilation. When the snails are pulled out of the water, they close themselves into the operculum, the horny covering of the shell which enables them to maintain an environment of high humidity within the shell and to survive for several hours.

The snails are brought by truck from the port in refrigerated cars stored in insulated containers (made of Styrofoam) to the commercial center, and from there, transferred to large refrigerators. Under optimal conditions, they can remain alive in refrigeration for a week until they are delivered to the fish stores. Under regular conditions of refrigeration, they can survive for at least 48 hours. The optimal conditions for keeping the murex alive are refrigerators with circulation at a temperature between six and eight degrees and a humidity level of 80-100%.

[17] M. Ra'anan, "Scientific and economic aspects in raising the snails for dyeing ritual fringes", *Al Atar 6,* 2000, pp. 84-86 (Hebrew).
[18] Ibid, pp. 73-74, 88.

Producing the raw material for dyeing

Cracking the shell

As we understand it, in the ancient world the "hunt" for snails usually consisted of three different activities: pulling the snails out of the ocean, cracking the shells, and removing the dye-containing glands. The craft of dyeing itself was apparently separate and was handed over to professional dyers. How these activities were combined can be deduced from some of the sources, for example, from the following law: "Our Rabbis taught: He who captures a purple-fish and crushes it is liable to one [sin-offering]; R. Judah said: He is liable to two, for R. Judah maintained: Crushing comes under the head of threshing"..[19] Connecting the activity of hunting with that of crushing confirms that both were done by the same person. Moreover, the fact that the Talmud explains that the reference is to a live snail shows that immediately afterwards, they remove the dye gland: "…because he is more pleased that it should be alive, so that the dye should be clearer" (than if the snail is dead).[20] Indeed our own experience shows that dye in a significant enough quantity to make it feasible to collect and worthy to use in dyeing cannot be produced from a dead snail. This also clarifies the words of the classical writers, that the snail hunters made every effort to crack the shells of the snails while they were still alive, because if the snails were dead, the dye was of poor quality.[21] It further emerges that the process of cracking the shell is relatively quick as compared to the job of removing the dye gland, so that working efficiently, the person who cracks the shell can also have a hand in the second stage.

Before beginning the work, one should spread a nylon drop cloth that will make it easier to remove the waste materials and maintain cleanliness and hygiene in the work environment. From our experience we have found that the snails should be placed on a

[19] BT, *Shabbat* 75a (Soncino translation)
[20] Ibid.
[21] Aristotle, IX, 126. P. Vitruvius, *On architecture* (F. Granger, trans.), Cambridge 1934: VII 13.

fixed, solid, and sturdy surface (not on a table) made of stone, cement, or asphalt (see Figure 1). A rough or pocked surface is best for laying out the murex. Breaking the shells is accomplished with an iron hammer with a broad head. The most suitable hammer will weigh 2-3 kilograms. The shell should be cracked with one short, precise blow above the area of the dye gland (hypobranchial gland). The snail cracking surface should be placed at a distance from people and objects that might be damaged by spatters of broken shell.

Figure 4: The author cracking the snail shell

The proficiency of the snail cracker is a decisive factor when it comes to removing the dye gland and fully extracting the material. In fact, it is preferable for the person cracking the shell to break it rather than shatter it, so that broken pieces of shell may be removed, and the gland taken out intact. A poorly directed blow or over-shattering will cause much of the material which is smeared over the snail's body parts to be lost, something that cannot be entirely avoided. A description of the work of snail fishermen was given by the Roman writer Aelian (175-235):

> When a fisherman after Purple Shellfish catches one not for human consumption but for dyeing wool, if the color from it is to remain fast, indelible, and capable of producing the genuine tint unadulterated, then he smashes it, shell and all, with one blow of a stone. But if the blow is too light and the creature is left still alive,

a second blow with the stone renders it useless for dyeing purposes. For the pain causes the fish to spend the dye, which is absorbed into the mass of flesh or escapes in some other way.[22]

Figure 5: Red-Mouthed Rock-shell,
area of the dye gland (hypobranchial gland).
(Photo: Zohar Amar©)

During the course of our work, we placed the shells from which the dye had been removed in a container, and with time, the remaining dye fluids accumulated at the bottom. In the final analysis there is a large depreciation of material, which the ancients apparently extracted by 'squeezing' the flesh of the snail and collecting the material from the craters on which they broke the snail shells, as Vitruvius noted in the 1st century BCE: "When the shells have been collected, they are broken up with iron tools. Owing to these beatings a purple ooze like a liquid teardrop is collected by bruising in a mortar".[23] This explains R. Judah's opinion that crushing the snail "is like threshing".[24] This work is also hinted at in the explanation given for snail hunters: (ibid, 26a) "Yogevim".[25]

[22] Aelian (ibid), XVI 1.
[23] Vitruvius, ibid.
[24] BT, *Shabbat* 75a.

These are those which catch hillazon [purple-fish for making dye] from the promontory of Tyre as far as Haifa." It seems that the activity of the 'Yogevim' refers to the work surfaces[26] – pits or hollows in the porous rock, on which they would place the murex when pounding and threshing them.

Figure 6: Spiny Dye-Murex,
area of the dye gland (hypobranchial gland).
(Photo: Zohar Amar©)

The cracking should be done in a shaded, well-ventilated area. The broken shells should be sent on for immediate removal of the dye glands or alternately, refrigerated. Prolonged exposure may attract flies and wasps, and over time, the process of fermentation and spoilage cause a strong foul odor and decomposition of the dye material. The dyeing process itself is also accompanied by a strong unpleasant odor. This bad smell was one of the features of the argaman dye works in ancient times, to the point where Strabo commented that the large number of dyeing plants in Tyre was making the city an unpleasant place to live.[27]

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[25] BT, *Shabbat* 26a.
[26] Perhaps from the word 'gevim': pits or presses, a place where grapes are trodden and wine is collected. Cf. commentary of *Metzudat David* on Jer. 52:15.
[27] *The Geography of Strabo*, H.L. Jones (trans.), London 1961, XVI, 2, 23, pp. 268-269.

Removing the dye gland

The dye glands should be removed intact, and to do this, they should be removed with the other tissue such as the gills still attached. This may be done with tweezers, scissors, or a scalpel. The gland should be placed in a container or directly on the drying surface or on a thin layer of coarse salt which helps absorb the fluids. Drying it using salt is not recommended: although it does not ultimately affect the production of dye, the raw material produced is less concentrated and its texture is uneven.

Handling the job of extracting the dye gland from the murex is one that leaves a lasting impression on the hands. The hands are dyed a strong, durable purple which is not easily removed, and color stains may remain on fingernails for two weeks after working with the dye. Thus, a law quoted in the name of R. Hoshaya Raba (3rd century) is explained in a realistic, down-to-earth way:

> R. Judah said: Also, anyone whose hands were dyed with woad or safflower or madder shall not bless the people with the priestly blessing, because people are accustomed to look at him when he does. R. Hoshaya the Great learns: If most of the people in the city work at this trade, then he is permitted to bless them, just as in the south, there are towns of dyers of argaman and their hands are stained with dye.[28]

[28] Tanhuma, Naso, 8. Another version: "Cities where they dye things purple and most of the people have their hands stained with dye".

Figure 7: Removing the hypobranchial gland. Note how fingers are stained with the purple dye.
(Photo: Zohar Amar©)

In addition, the person who is engaged in removing the dye glands has a strong smell of fish clinging to him, and this corresponds to what is written in an early Egyptian source: "His hands reek, they smell like rotten fish".[29] Holding the murex, particularly of the trunculus type, causes wounds on the fingers and leaves them scarred. The hands of those who were engaged in this work, then, could be identified by three signs: the color, the smell, and the scars. Using gloves could significantly prevent the side effects of coloration and smell. Also removing the dye glands should take place in a shaded, well-ventilated place. To prevent the material from spoiling, it must be sent directly either to drying or refrigeration. In natural dyeing, where the dye glands which were exposed in the cracking process are deliberately fermented with the flesh of the dead snail for a prolonged time, use of a fume cupboard is recommended.

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[29] Bruin, ibid, p. 303.

Drying

Drying the dye glands makes it possible to preserve the raw material for a longer time and to prevent its spoiling. The best drying implement is one that has a fan element such as a hair dryer or using heating plates, although this is only good for a small quality of murex. Drying on a large scale requires a large drying oven with several shelves. The oven should have an air circulation system or the possibility of installing a fume hood. If the dye glands are placed directly on the drying shelves, some of the dye material is likely to adhere to them, and it may be removed with a spatula and then used. In any case, the drying process ends when the moisture in the glands evaporates and a brittle raw material is obtained that is easily ground into powder.

Figure 8: Drying over – On the top shelf are the dried glands of the Banded Dye-murex and on the bottom shelf, of the Spiny Dye-murex
(Photo: Zohar Amar©)

The drying temperature is set in accordance with needs. Some think that at a temperature of over 70 degrees the enzyme purpurase that causes the color to appear, and so it should be dried at a relatively low temperature. A controlled drying process at 50 degrees lasts at least 24 hours. Increasing the temperature naturally speeds up the process. In an experiment that we conducted, it emerged that heating the glands of the Murex trunculus

after preliminary drying at a temperature of 100 degrees for an hour does not destroy their dye and allows the production of dye of good quality. In another experiment, the raw glands were burned at a temperature at 105 degrees for two hours, and also in this case, it was proven that their dye was not destroyed. [30] Other ramifications of drying the dye glands at a too-high temperature should be tested.

The dye glands may be dried in the sun, but this is a prolonged process that takes several days and is accompanied by a bad smell which can attract flies and wasps. Drying the dye glands and exposing them for a prolonged period to the sun will accelerate the process of dyeing the raw material to purple. It is possible that in some cases this process can prevent obtaining other desirable colors. In other words, the conditions of exposure to oxygen and to light at all stages of the work: cracking, removing dye glands, and drying must be determined in advance.

Data on material and work output

1. **Number of snails per kilogram and their weight**: In one kilogram of Murex brandaris there are some 60 pieces of average size, occasionally up to 75-80 pieces of varying sizes. The average weight of the adult snails is some 20 grams, and the average length reaches up to 7.5-8 cm. and a maximum width of 4.5 cm.

Packages of Murex trunculus contain some 20-40 items of medium or large size in every kilogram. The weight of the individual items checked ranges form 10-105 grams each, and the average weight of one piece is 55-65 grams. The largest items reach a length of 8.5 cm.

[30] Yoel Goverman told me that at the Petil Techelet Association, they sometimes cook the raw glands to vaporize some of the water and accelerate the drying process, which shows that high temperature does not destroy the dye.

Packages of Murex haemastoma contain 20-30 pieces of medium or large size in every kilogram. The weight of the individual pieces tested was 37-80 grams, and the average weight of one item was some 40 grams. The largest items reached a length of 8.5 cm.

2. **Raw material (dye glands) which is not clean (general average assessment of several dozen tests**): The average weight of a fresh dye gland of adult Murex trunculus is 1-2 grams. The weight of a fresh dye gland of Murex haemastoma is 0.5-0.7 grams. The weight of a dye gland of the Murex brandaris is 0.1-0.4 grams, the average is only 0.2 grams (some 10% of the gland of the Murex brandaris and some 25% of the gland of the Murex haemastoma). However, in actuality when the removal of the glands is carried out at a rapid pace, it is hard to get a "clean" fresh gland, so that even in this species, the weight of the dye gland may reach 2 grams. This weight includes the tissues attached to the gland (like the gills and bits of flesh), and these add-ons actually constitute most of the weight. This is reflected in the quantity of dry material that is obtained at the end of the process.

Out of 100 kilograms of Murex brandaris (some 6,000 pieces), one may obtain about 3 kilograms of fresh glands (including the attached tissue), and of this, approximately one kilogram of dried gland is obtained at the end (10 grams of dye per kilogram of snails). Alternately, out of 100 kilograms of Murex brandaris (some 3,000 pieces) one may obtain some 4 kilograms of fresh glands (including attached tissue), and this will ultimately produce about 1.250 kilograms of dried gland (12.5 grams of dye material from one kilogram of snails).

3. **Work output**: These figures are not absolute and vary with the following parameters:

a. Size of snail
b. Quality of cracking
c. Number of workers and level of proficiency
d. Miscellaneous: working environment, tools, weather, and more.

Because of this, all the calculations given in this study are by way of general estimate rather than a precise computation. There is no doubt that the most important parameter is

the skill of the workers, whose output grew with their acquired experience (within several hours). Activity on an industrial scale requires effective teamwork and includes two main activities - breaking the shells and removing the dye glands.

Based on several measurements and estimates that we made, it seems that two skilled workers can extract dye from one kilogram of Murex brandaris within 15 minutes. For the Murex trunculus, where the number of snails per kilogram is smaller, two skilled workers can extract raw material from one kilogram in 10-12 minutes. This output can be maintained over a full working day (eight hours with short breaks).

Cost of raw material and labor

A calculation of the cost of the raw material for the royal purple dye is composed of several components:

1. The cost of the murex: as for every product, the price fluctuates according to supply and demand, availability of the murex (depends on weather conditions and season of year) and more.[31]
2. Payment to workers who crack the shells and extract the glands.
3. Instruments, tools, and additional expenses (airplane fare, renting a workspace, etc.).

The dye material is found in tiny quantities in the gland, and this requires large number of snails. The researchers who handled the quantities of material that could be produced from the snails and accordingly, to estimate the cost of the dye, came up with different figures. According to one calculation (based on Pliny's analysis), they produced 500

[31] To illustrate: the average price of one kilogram of Murex trunculus in the market today can be as high as €6.

libras [12 ounces] of liquid extract from 8000 libras of raw material, i.e., 62.5% of the liquid was not pure.[32]

According to the account by Freidlander, who is frequently cited in the research, to produce 1.4 grams of pure liquid dye, 12,000 Spiny Dye murex are required.[33]
On the basis of this figure, other scholars estimated that the cost of one gram according to the 1961 prices, in the year 200 BCE should have cost approximately $300,000.[34] We are of the opinion that these estimates are exaggerated and not firmly grounded, and the calculations may have been based on experiments that were done using wasteful and inefficient methods of extraction.

According to the experiments conducted at the University of Beirut on Murex trunculus, every snail is capable of yielding some 0.1 milligrams of pure material.[35] This material is very concentrated and dyes well. From the people at "*Petil Tekhelet"* who have much experience in dyeing wool using Murex trunculus, it emerges that in dyeing one set of tzitzit (the heavy woolen fringes to be dyed weigh approximately 30 grams), 25-30 snails are used. According to the calculations in our study, one gram of wool may undergo a good quality dyeing using 0.5 grams of dried material from the Murex trunculus.

In any case, even according to the most cautious and conservative estimates, it is a very expensive dye. These prices explain the fact that there were not many who were able to afford to buy clothes dyed with genuine royal purple, and that an industry of counterfeiting and cheap imitation developed at the time.

[32] A. Neuburger, *The Technical Arts and Sciences of the Ancients* (H.L. Brose trans.), New York – London 1969, p. 188.
[33] P. Friedländer, Über den Farbstoff des antiken Purpurs aus murex brandaris, *Berichte der Deutschen Chemische Gesellschaft*, 42 (1909), p. 766
[34] Jensen, p. 109. Other researchers estimated that the value of a gram of genuine royal purple dye was worth 10-20 grams of gold, see Bruin, p. 300.
[35] Bruin, p. 307.

Summary

This applied research traces the craft of the ancient snail shell cracker, the technique for removing the dye gland, and all the other steps of the procedure. The study makes it possible to understand various aspects related to dyeing with royal purple that are mentioned in the historical sources, and provides a more realistic dimension to estimating the figures pertaining to producing the dye material from snails and its cost.

Figure 9: Samples of dyes obtained from the raw glands of murex: (from right to left): Banded Dye-Murex (1) under normal lighting conditions and (2) after exposure to sunlight; Spiny Dye-Murex under normal lighting conditions (3) and after exposure to sunlight (4,5)
(Photo: Shahar Cohen ©)

Figure 10: Samples of dyes obtained from the Red-Mouthed Rock-shell: The red hues were obtained under normal lighting conditions and the green, after exposure to sunlight
(Photo: Shahar Cohen ©)